Johns Hopkins University
School of Nursing
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Introduction to the
Unified Medical Language System

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Outline

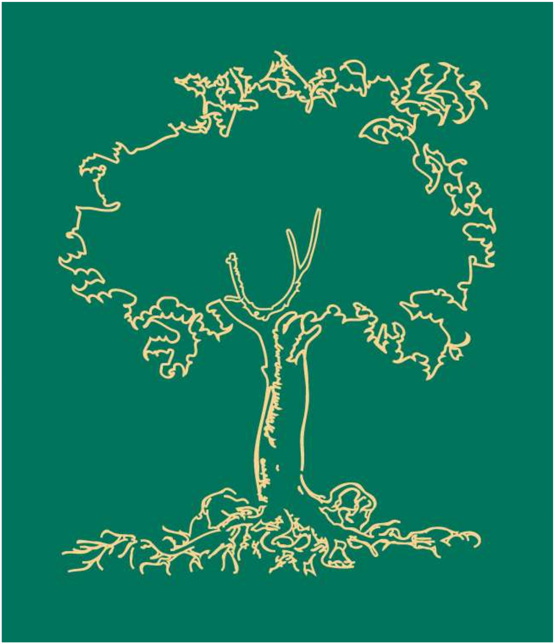
- Introduction
- Overview through an example
- The three UMLS Knowledge Sources
  - UMLS Metathesaurus
  - UMLS Semantic Network
  - SPECIALIST Lexicon and lexical tools
- UMLS in action: *MetaMap*

NLM

Introduction

What does UMLS stand for?

- Unified
- Medical
- Language
- System



UMLS®
Unified Medical Language System®
UMLS Metathesaurus®

NLM

Motivation

- Started in 1986
- National Library of Medicine
- “Long-term R&D project”
- Complementary to IAIMS

(Integrated Academic
Information Management Systems)

«[…] the UMLS project is an effort to overcome two significant barriers to effective retrieval of machine-readable information.

- The first is the variety of ways the same concepts are expressed in different machine-readable sources and by different people.
- The second is the distribution of useful information among many disparate databases and systems.»

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The UMLS in practice

- Database
  - Series of relational files
- Interfaces
  - Web interface: Knowledge Source Server (UMLSKS)
  - Application programming interfaces (Java and XML-based)
- Applications
  - lvg (lexical programs)
  - MetamorphoSys (installation and customization)

The UMLS is *not* an end-user application

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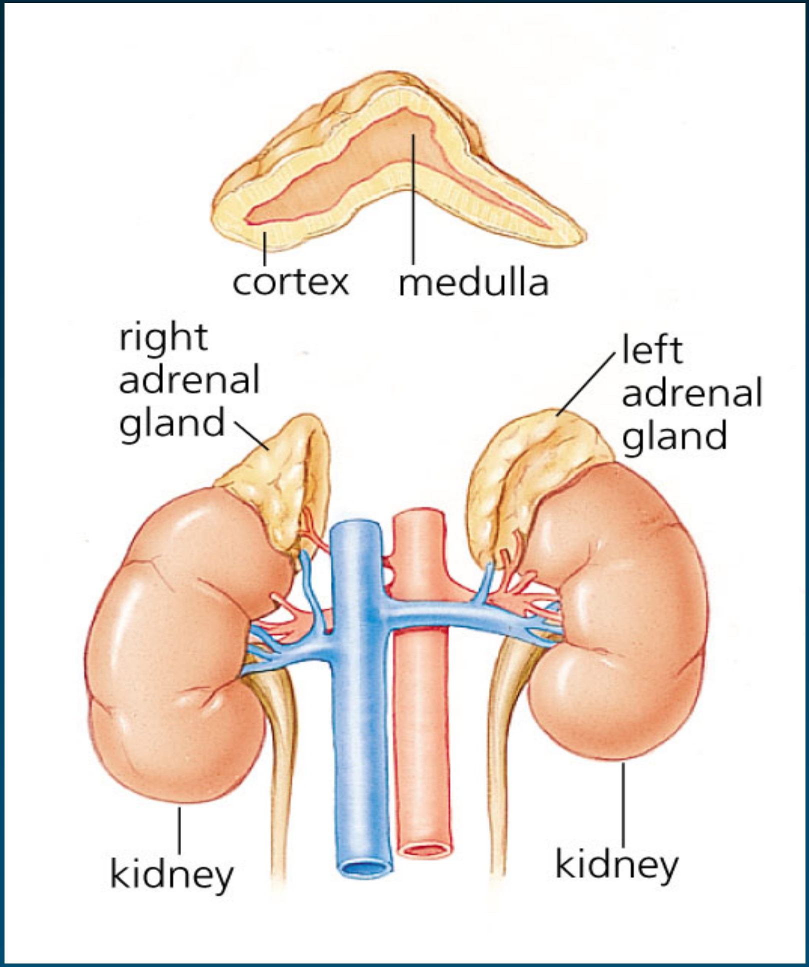
Overview through an example

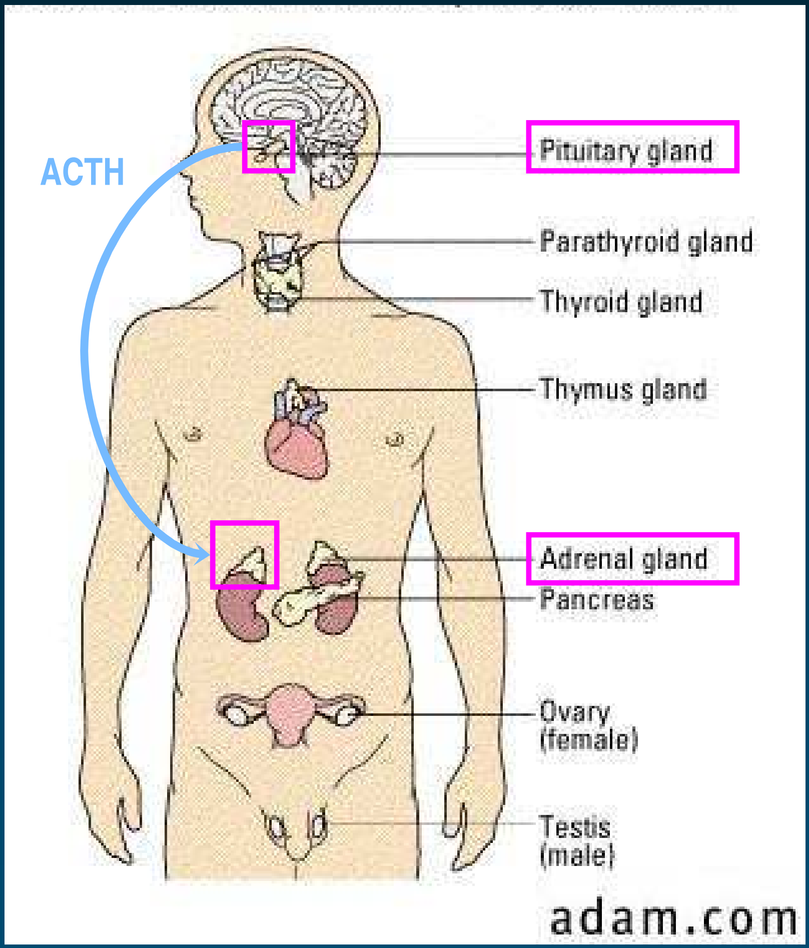
Addison's disease

- Addison's disease is a rare endocrine disorder
- Addison's disease occurs when the adrenal glands do not produce enough of the hormone cortisol
- For this reason, the disease is sometimes called chronic adrenal insufficiency, or hypocortisolism



Adrenal insufficiency Clinical variants

- Primary / Secondary
  - Primary: lesion of the adrenal glands themselves
  - Secondary: inadequate secretion of ACTH by the pituitary gland
- Acute / Chronic
- Isolated / Polyendocrine deficiency syndrome



Addison’s disease: Symptoms

- Fatigue
- Weakness
- Low blood pressure
- Pigmentation of the skin (exposed and non-exposed parts of the body)
- …

AD in medical vocabularies

- Synonyms: different terms

● Addisonian syndrome	eponym
● Bronzed disease	symptoms
● Addison melanoderma	
● Asthenia pigmentosa	
● Primary adrenal deficiency	clinical variants
● Primary adrenal insufficiency	
● Primary adrenocortical insufficiency	
● Chronic adrenocortical insufficiency	

- Contexts: different hierarchies

Organize terms

- Synonymous terms clustered into a concept
- Preferred term
- Unique identifier (CUI)

Adrenal gland diseases	MeSH	D000307
Adrenal disorder	AOD	0000005418
Disorder of adrenal gland	Read	C15z.
Diseases of the adrenal glands	SNOMED	DB-70000

C0001621

Adrenal Gland Diseases

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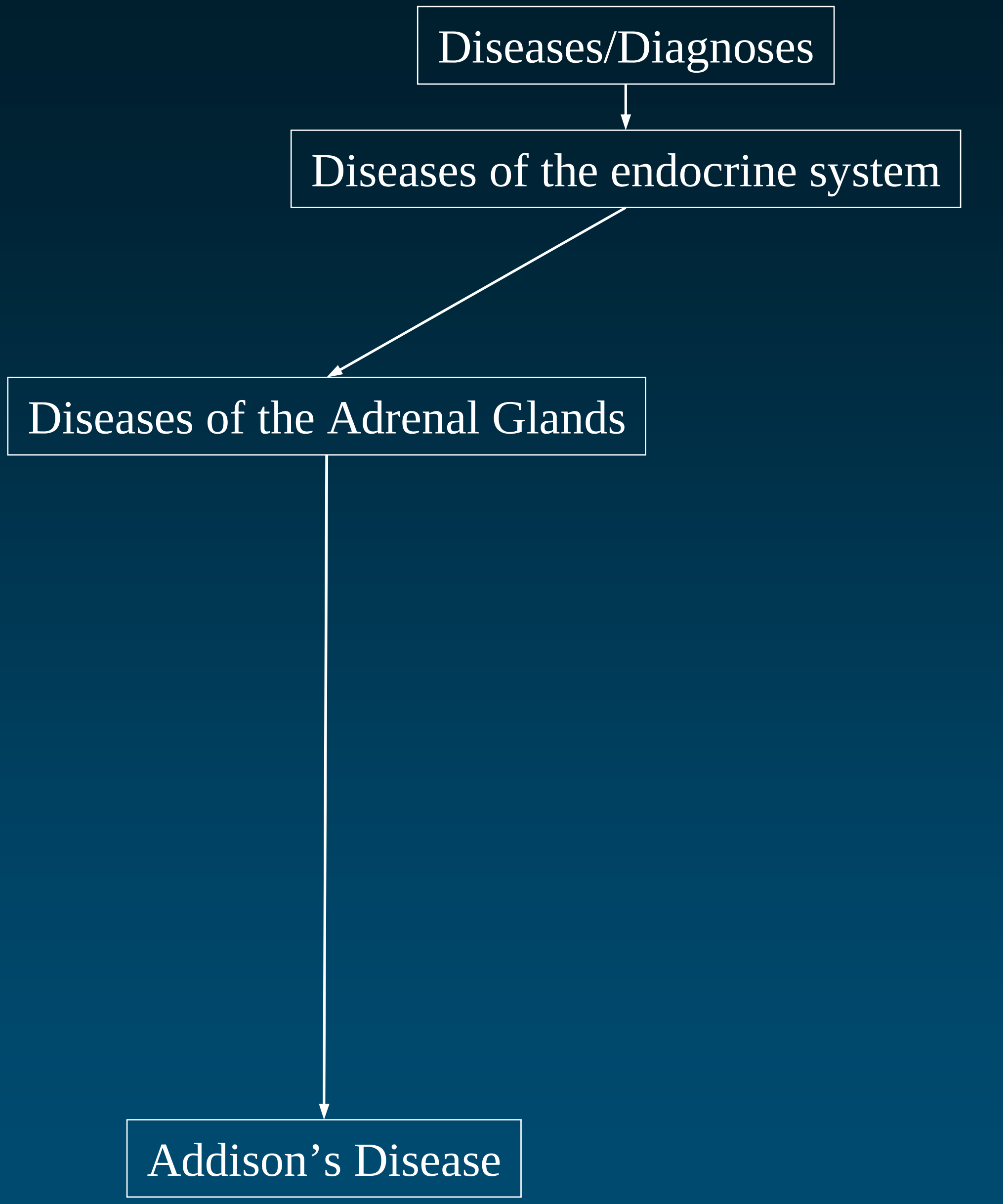
SNOMED International



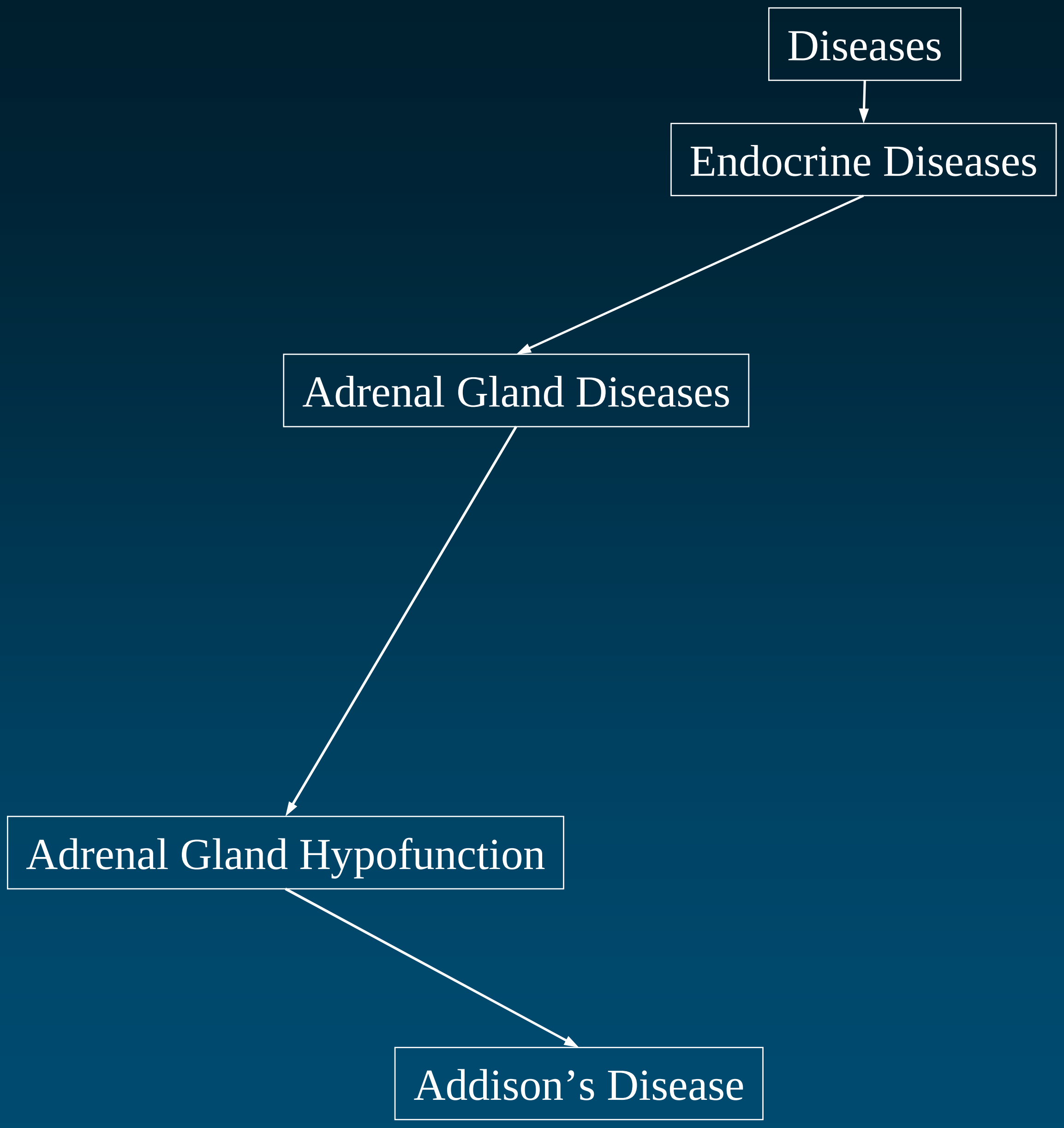
Diseases/Diagnoses

Diseases of the endocrine system

Diseases of the Adrenal Glands

Addison’s Disease

MeSH



Diseases

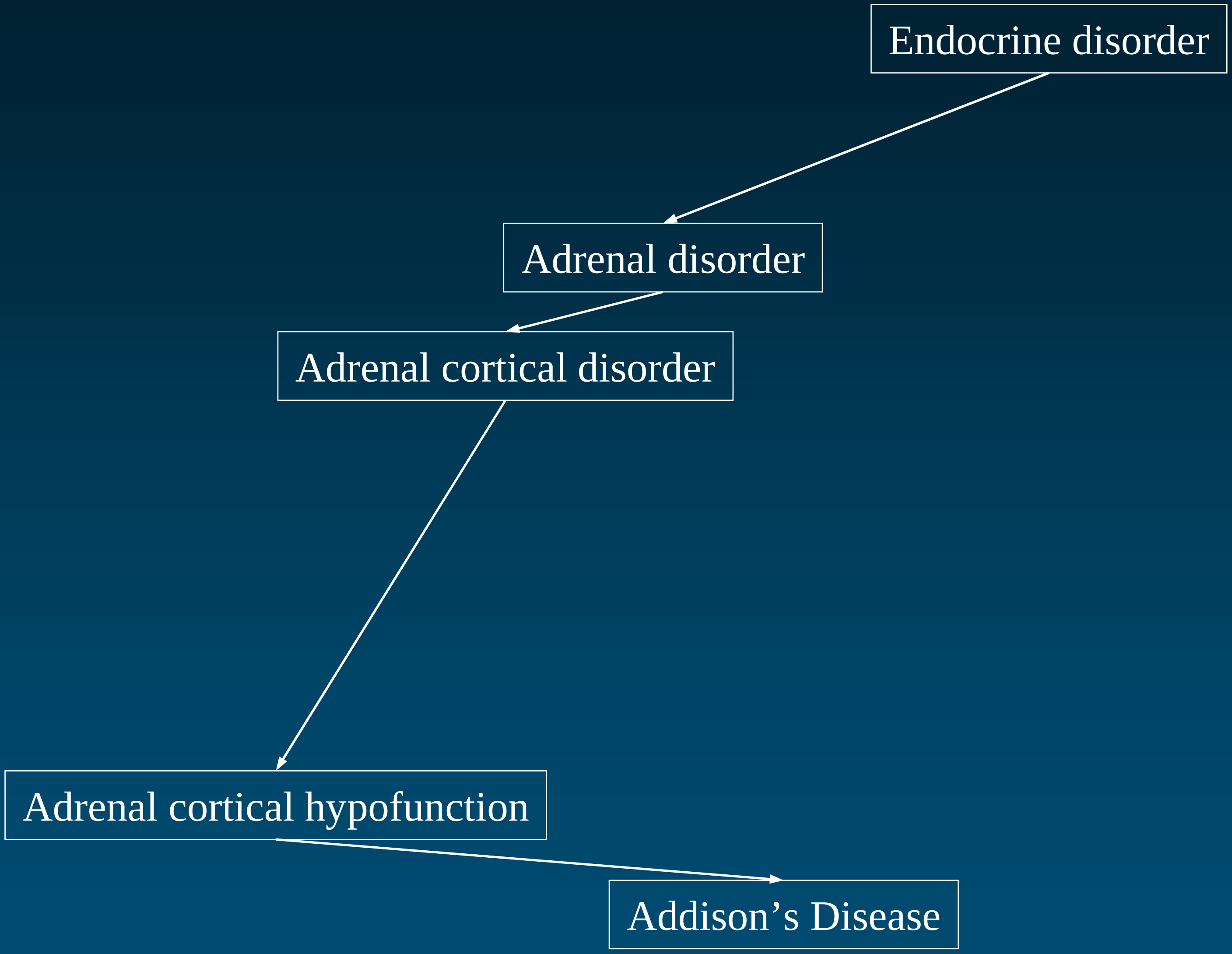
Endocrine Diseases

Adrenal Gland Diseases

Adrenal Gland Hypofunction

Addison’s Disease

AOD



Endocrine disorder

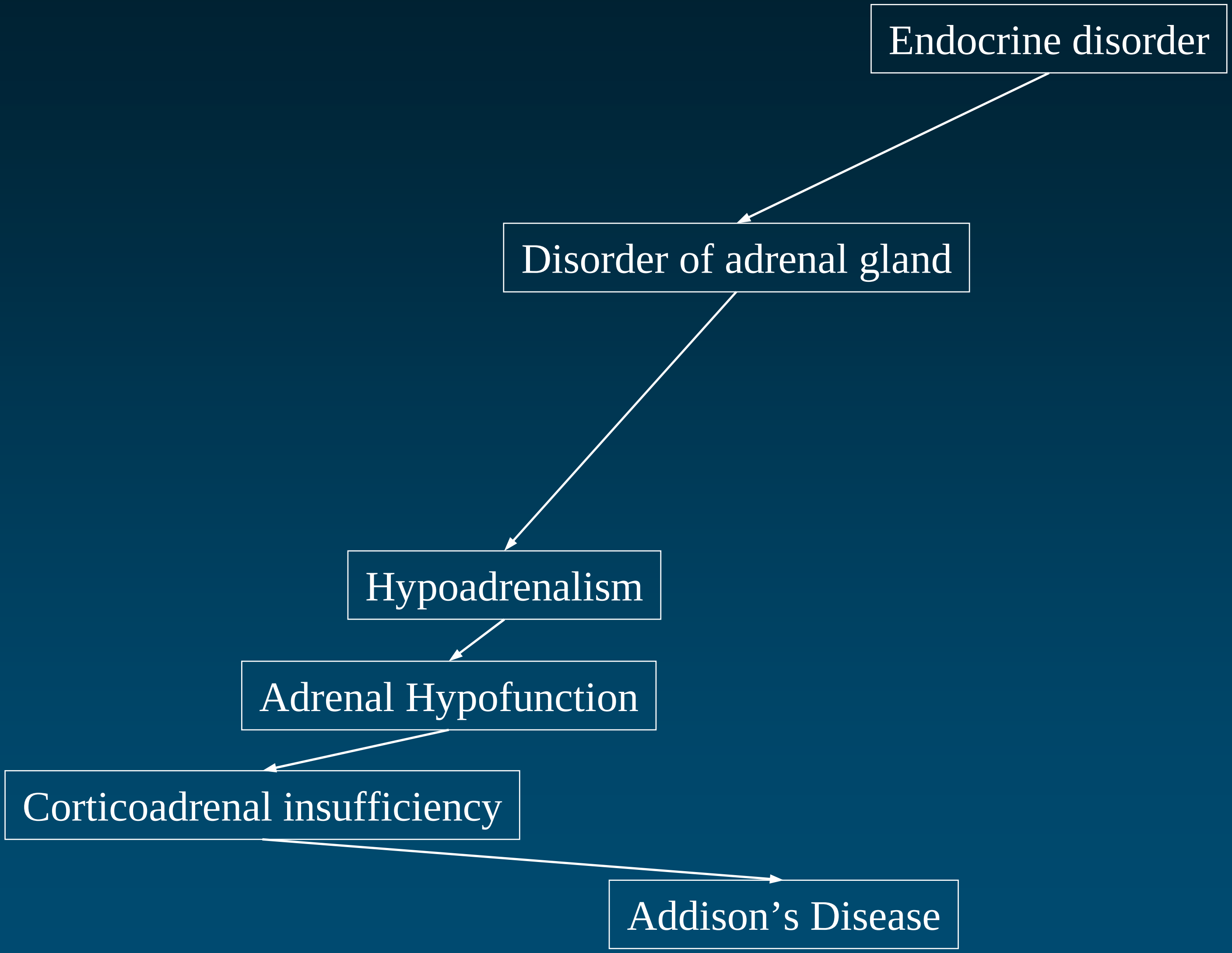
Adrenal disorder

Adrenal cortical disorder

Adrenal cortical hypofunction

Addison’s Disease

Read Codes



Endocrine disorder

Disorder of adrenal gland

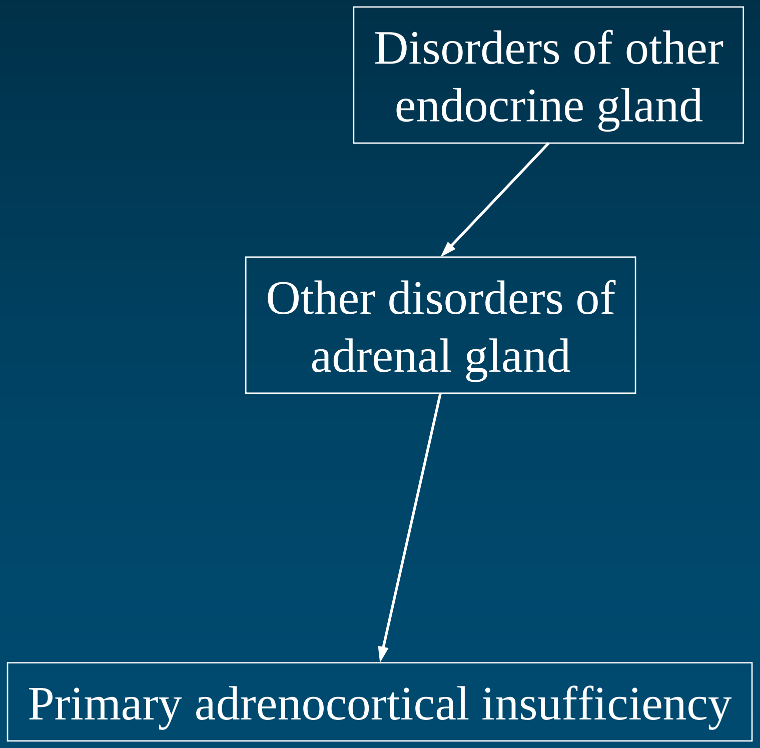
Hypoadrenalism

Adrenal Hypofunction

Corticoadrenal insufficiency

Addison’s Disease

ICD-10



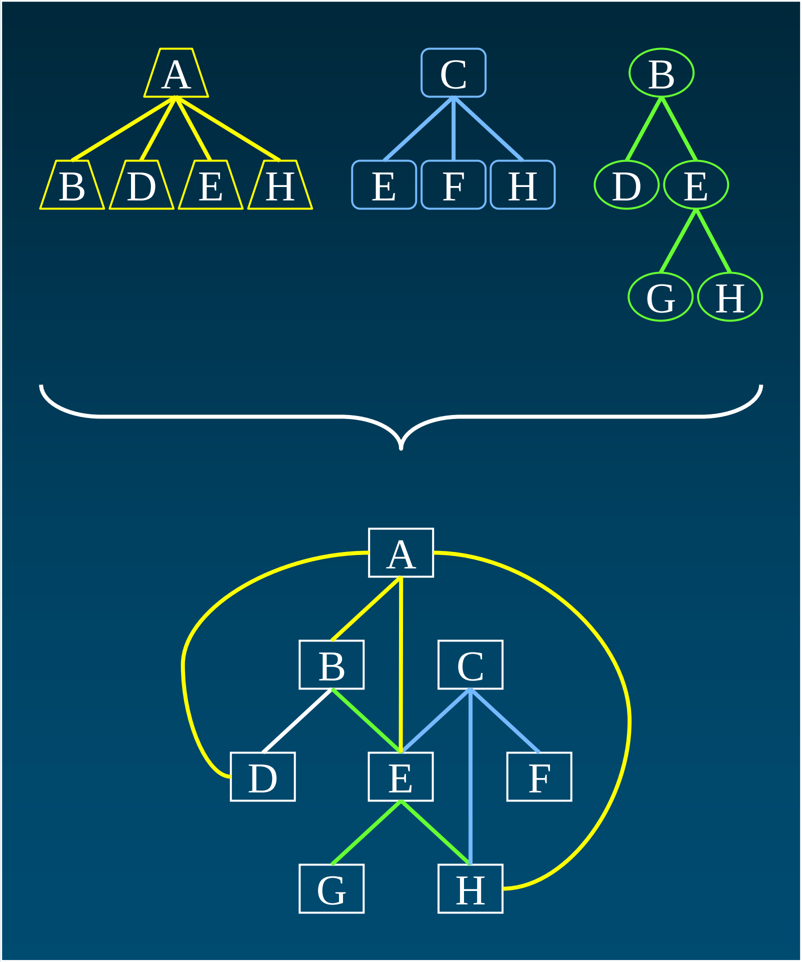
Disorders of other endocrine gland

Other disorders of adrenal gland

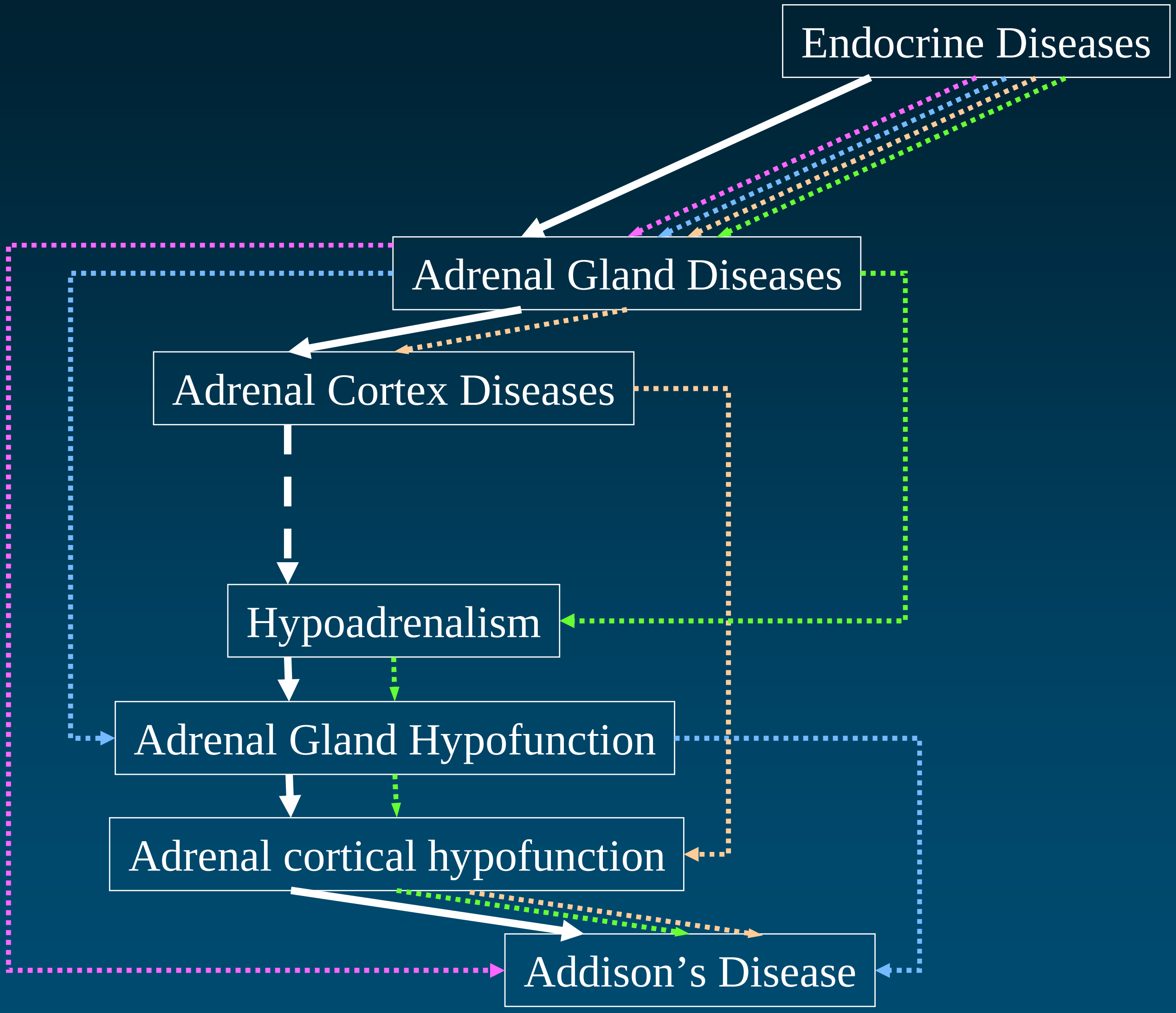
Primary adrenocortical insufficiency

Organize concepts

- Inter-concept relationships: hierarchies from the source vocabularies
- Redundancy: multiple paths
- One graph instead of multiple trees (multiple inheritance)



organize concepts

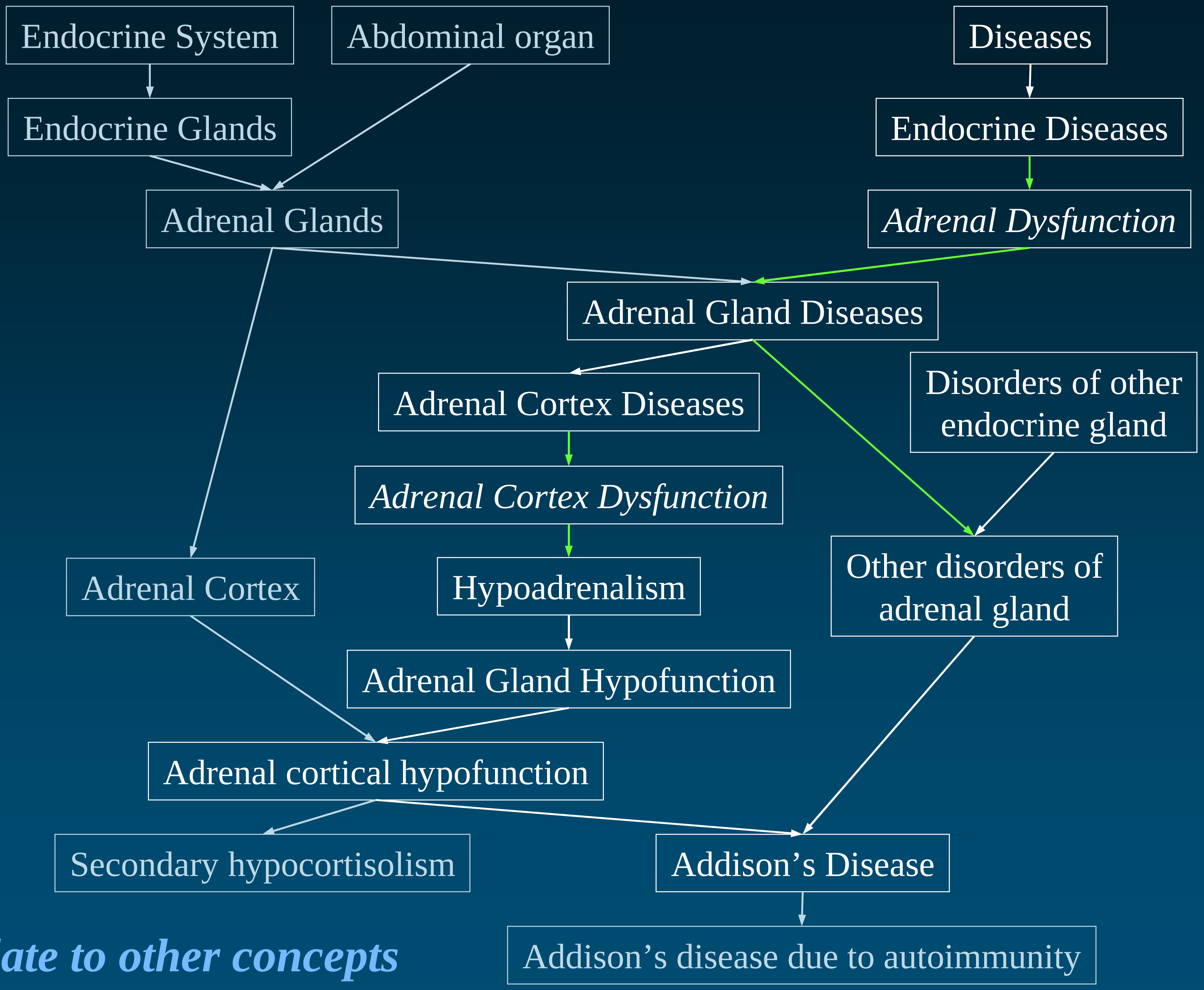


SNOMED
MeSH
AOD
Read Codes

UMLS

Relate to other concepts

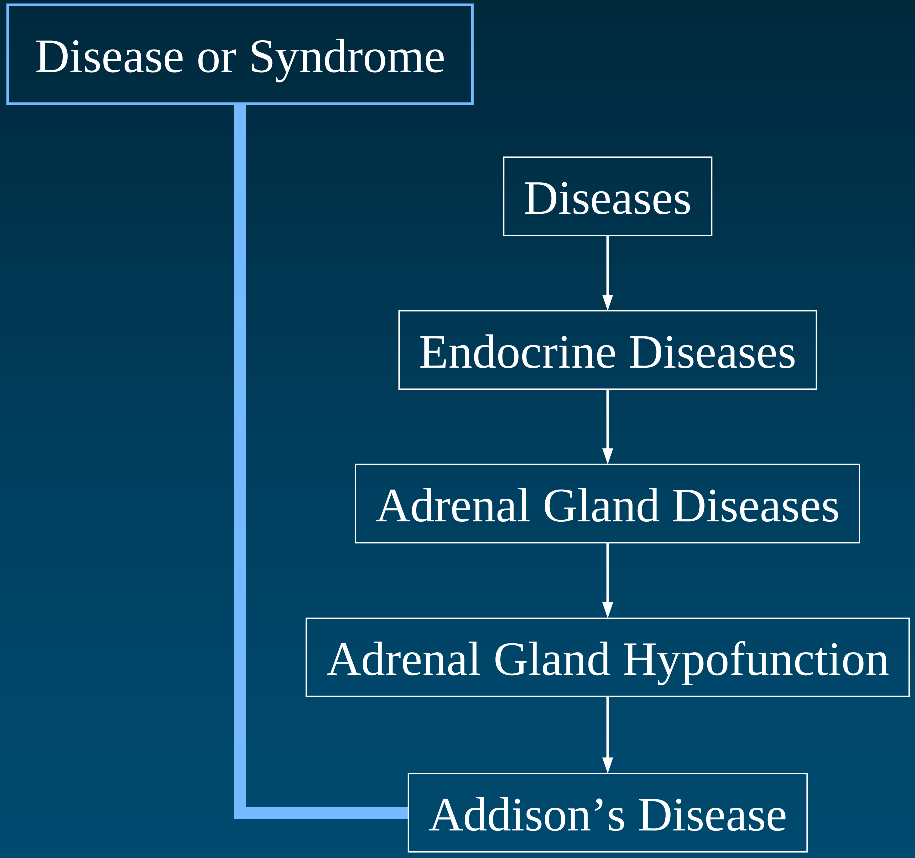
- Additional hierarchical relationships
  - link to other trees
  - make relationships explicit
- Non-hierarchical relationships
- Co-occurring concepts
- Mapping relationships


Endocrine System
Abdominal organ
Diseases
Endocrine Glands
Endocrine Diseases
Adrenal Glands
Adrenal Dysfunction
Adrenal Gland Diseases
Adrenal Cortex Diseases
Disorders of other endocrine gland
Adrenal Cortex Dysfunction
Adrenal Cortex
Hypoadrenalism
Other disorders of adrenal gland
Adrenal Gland Hypofunction
Adrenal cortical hypofunction
Secondary hypocortisolism
Addison’s Disease
Addison’s disease due to autoimmunity

relate to other concepts

Categorize concepts

- High-level categories (semantic types)
- Assigned by the Metathesaurus editors
- Independently of the hierarchies in which these concepts are located



Disease or Syndrome

Diseases

Endocrine Diseases

Adrenal Gland Diseases

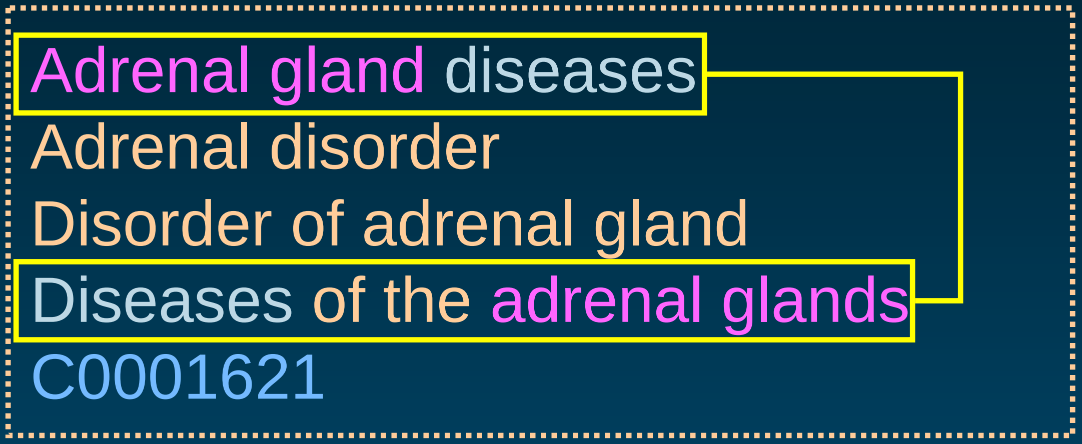
Adrenal Gland Hypofunction

Addison’s Disease

How do they do that?

- Lexical knowledge
- Semantic pre-processing
- UMLS editors

Lexical knowledge



Adrenal gland diseases

Adrenal disorder

Disorder of adrenal gland

Diseases of the adrenal glands

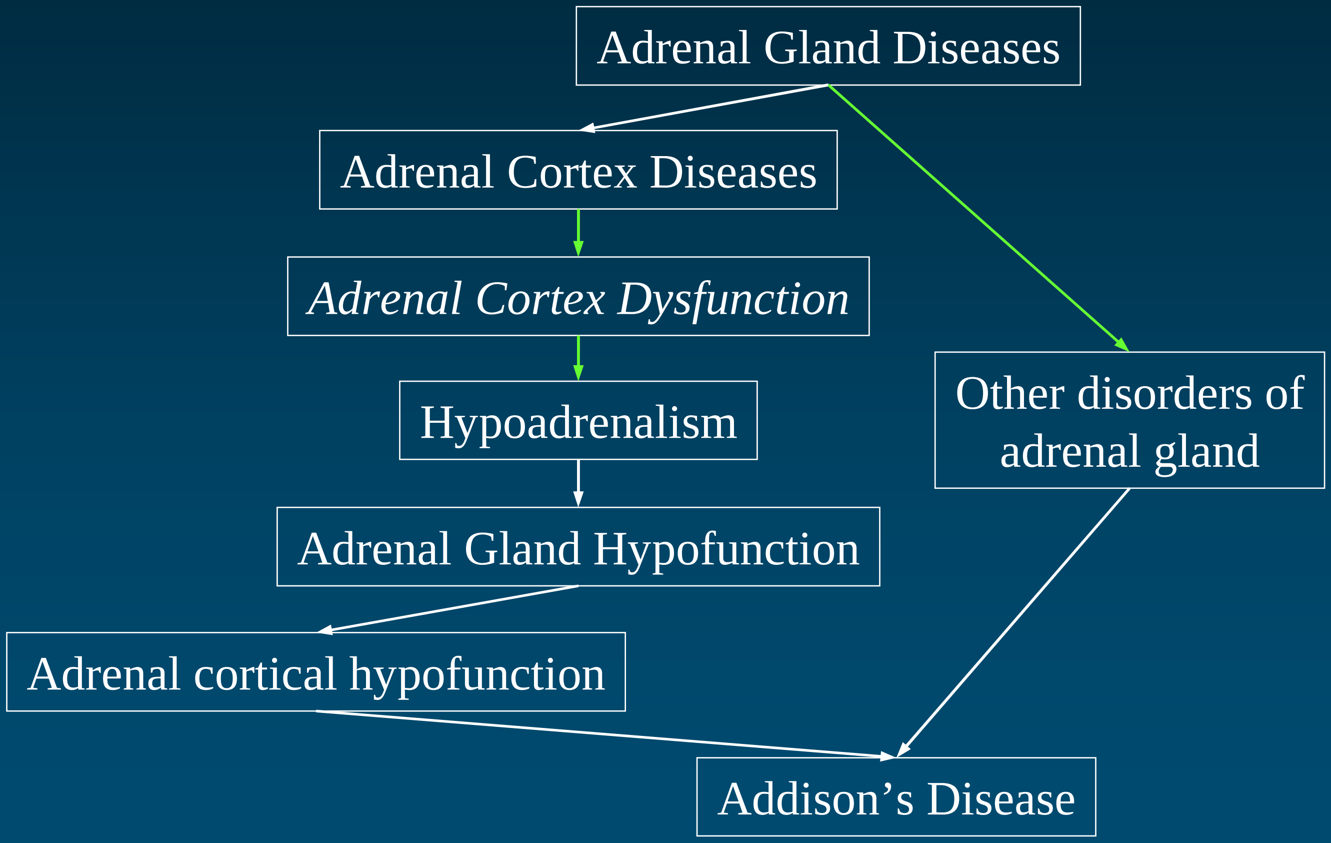
C0001621

Semantic pre-processing

- Metadata in the source vocabularies

- Tentative categorization
- Positive (or negative) evidence for tentative synonymy relations based on lexical features

Additional knowledge: UMLS editors



Adrenal Gland Diseases

Adrenal Cortex Diseases

Adrenal Cortex Dysfunction

Hypoadrenalism

Adrenal Gland Hypofunction

Adrenal cortical hypofunction

Other disorders of adrenal gland

Addison’s Disease

UMLS Summary

- Synonymous terms clustered into concepts
- Unique identifier

- Finer granularity
- Broader scope
- Additional hierarchical relationships
- Semantic categorization

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UMLS Knowledge Sources

UMLS 3 components

- Metathesaurus
  - Concepts
  - Inter-concept relationships
- Semantic Network
  - Semantic types
  - Semantic network relationships
- Lexical resources
  - SPECIALIST Lexicon
  - Lexical tools

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UMLS Metathesaurus

Metathesaurus Basic organization

- Concepts
  - Synonymous terms are clustered into a concept
  - Properties are attached to concepts, e.g.,
    - Unique identifier
    - Definition
- Relations
  - Concepts are related to other concepts
  - Properties are attached to relations, e.g.,
    - Type of relationship
    - Source

Source Vocabularies

(2004AB)

- 134 source vocabularies
  - 126 contributing concept names
- 73 families of vocabularies
  - multiple translations (e.g., MeSH, ICPC, ICD-10)
  - variants (American-English equivalents, Australian extension/adaptation)
  - subsequent editions usually considered distinct families (ICD: 9-10; DSM: IIIR-IV)
- Broad coverage of biomedicine
- Common presentation

Biomedical terminologies

- General vocabularies
  - anatomy (UWDA, Neuronames)
  - drugs (RxNorm, First DataBank, Micromedex)
  - medical devices (UMD, SPN)
- Several perspectives
  - clinical terms (SNOMED CT)
  - information sciences (MeSH, CRISP)
  - administrative terminologies (ICD-9-CM, CPT-4)
  - data exchange terminologies (HL7, LOINC)

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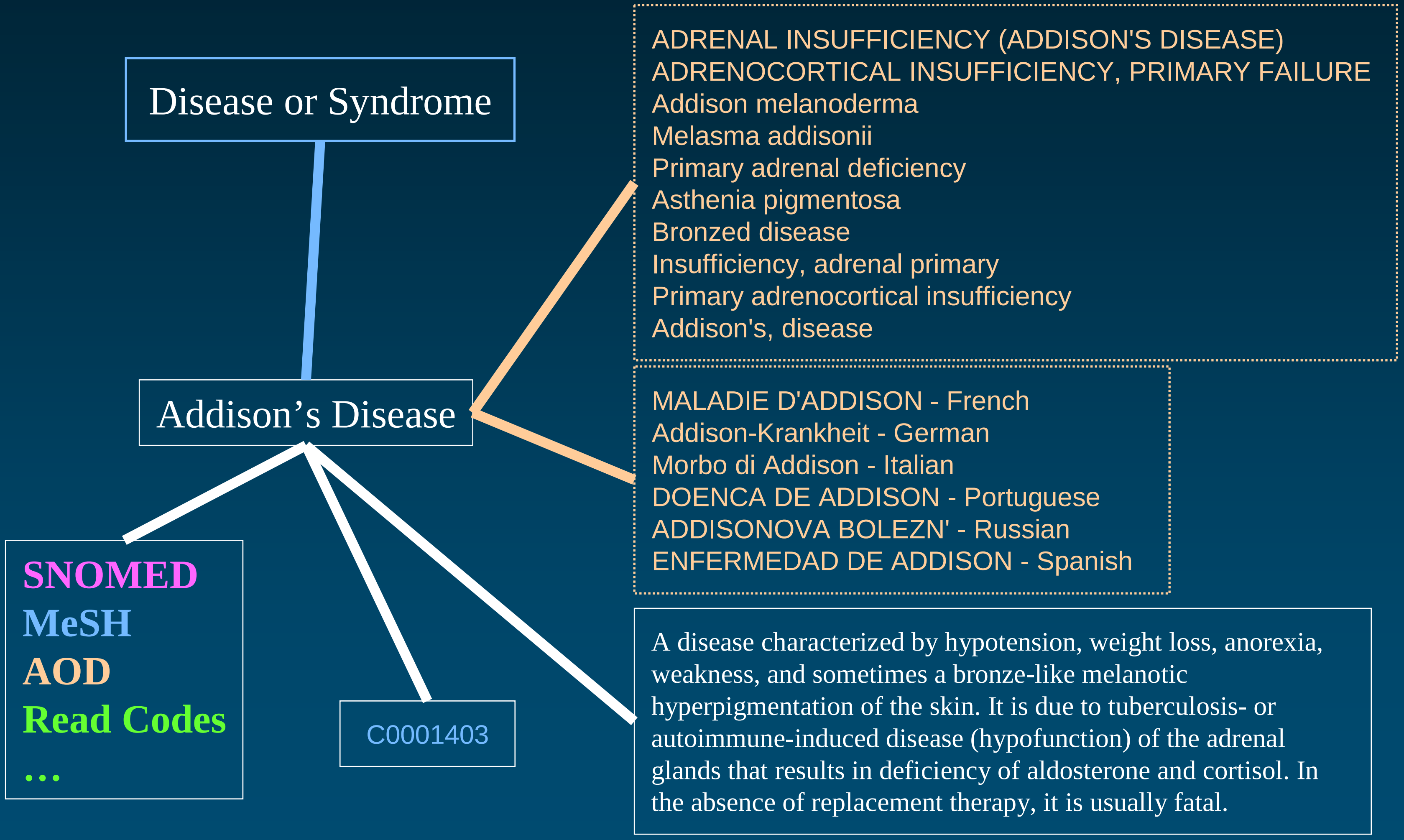
Biomedical terminologies (cont'd)

- Specialized vocabularies
  - nursing (NIC, NOC, NANDA, Omaha, PCDS)
  - dentistry (CDT)
  - oncology (PDQ)
  - psychiatry (DSM, APA)
  - adverse reactions (COSTART, WHO ART)
  - primary care (ICPC)
- Terminology of knowledge bases (AI/Rheum, DXplain, QMR)

The UMLS serves as a vehicle for the regulatory standards (HIPAA, CHI)

Addison’s Disease: Concept



Disease or Syndrome

Addison’s Disease

ADRENAL INSUFFICIENCY (ADDISON'S DISEASE)
ADRENOCORTICAL INSUFFICIENCY, PRIMARY FAILURE
Addison melanoderma
Melasma addisonii
Primary adrenal deficiency
Asthenia pigmentosa
Bronzed disease
Insufficiency, adrenal primary
Primary adrenocortical insufficiency
Addison's, disease

MALADIE D'ADDISON - French
Addison-Krankheit - German
Morbo di Addison - Italian
DOENCA DE ADDISON - Portuguese
ADDISONOVA BOLEZN' - Russian
ENFERMEDAD DE ADDISON - Spanish

SNOMED
MeSH
AOD
Read Codes
…

C0001403

A disease characterized by hypotension, weight loss, anorexia, weakness, and sometimes a bronze-like melanotic hyperpigmentation of the skin. It is due to tuberculosis- or autoimmune-induced disease (hypofunction) of the adrenal glands that results in deficiency of aldosterone and cortisol. In the absence of replacement therapy, it is usually fatal.

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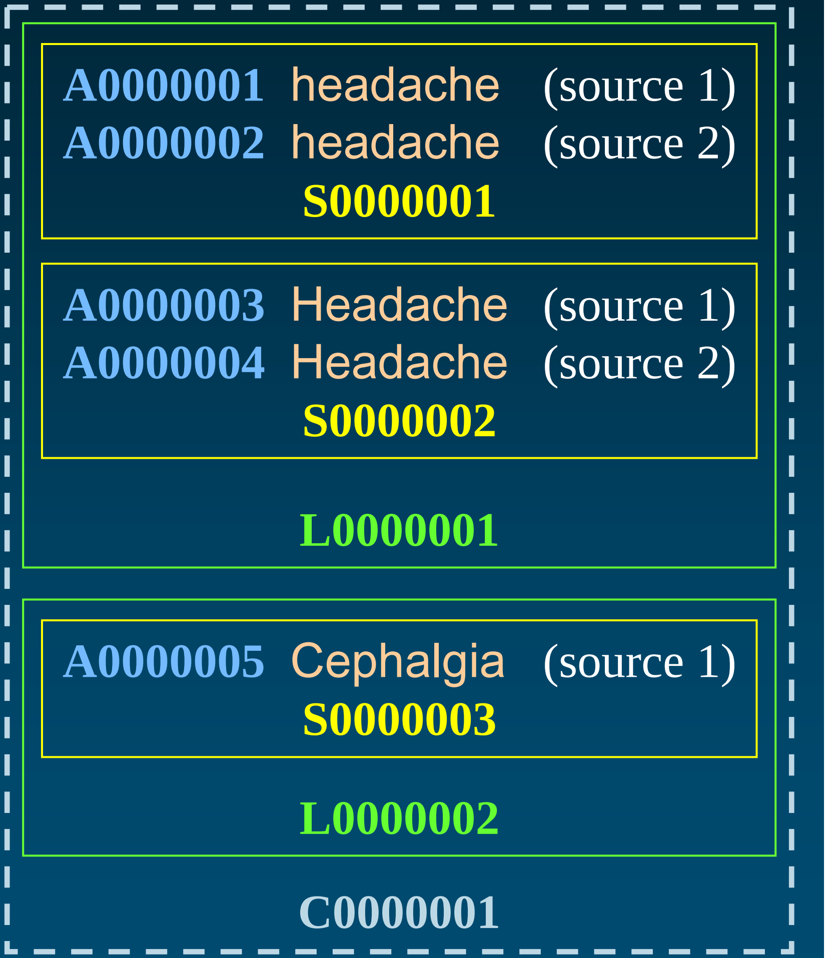
Metathesaurus Concepts (2004AB)

- Concept (> 1M) CUI
  - Set of synonymous concept names
- Term (> 3.8 M) LUI
  - Set of normalized names
- String (> 4.3M) SUI
  - Distinct concept name
- Atom (> 5.1M) AUI
  - Concept name in a given source



A0000001 headache (source 1)
A0000002 headache (source 2)
S0000001

A0000003 Headache (source 1)
A0000004 Headache (source 2)
S0000002

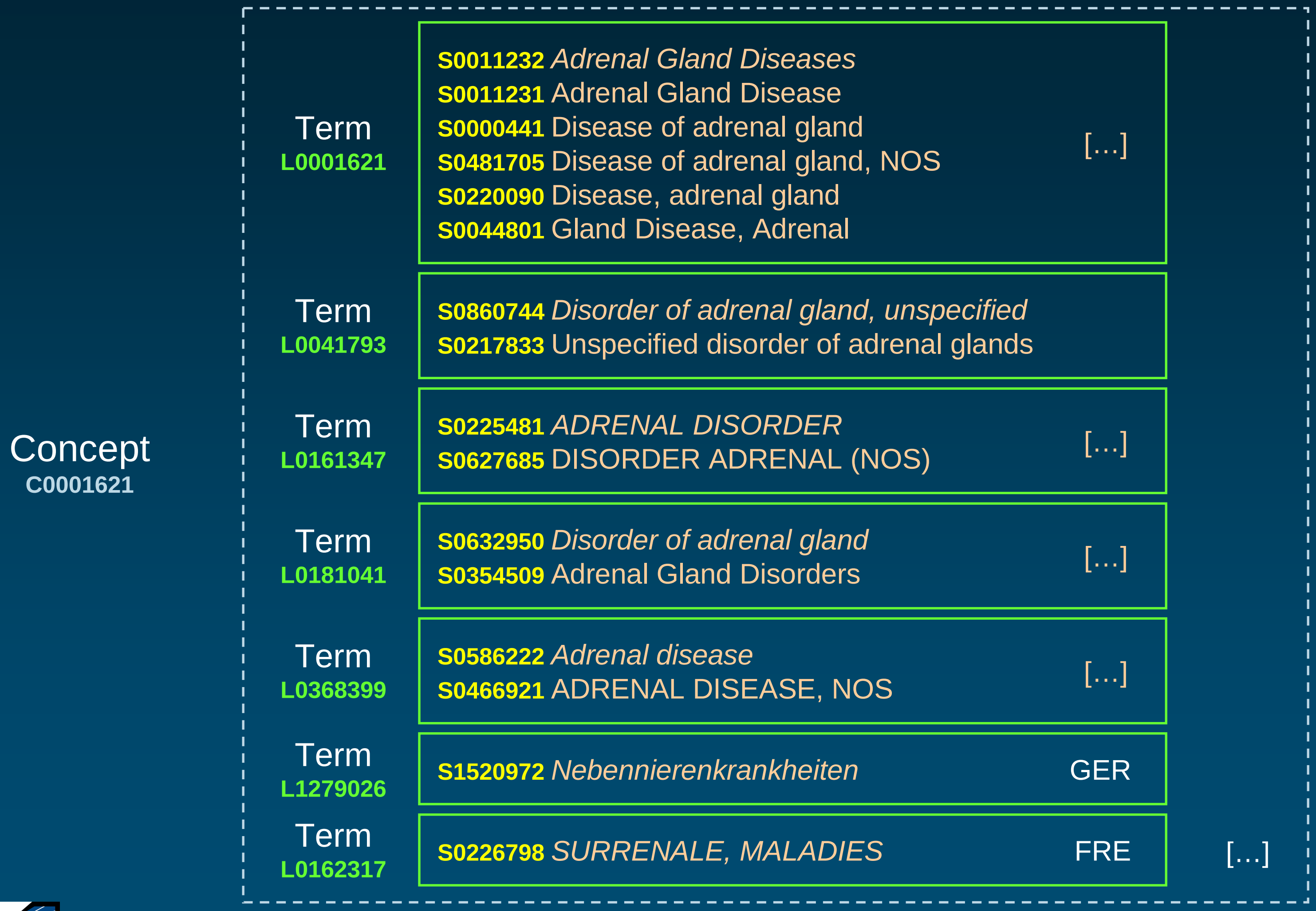
L0000001

A0000005 Cephalgia (source 1)
S0000003

L0000002

C0000001

Cluster of synonymous terms



Concept
C0001621

Term
L0001621

S0011232 *Adrenal Gland Diseases*
S0011231 Adrenal Gland Disease
S0000441 Disease of adrenal gland
S0481705 Disease of adrenal gland, NOS
S0220090 Disease, adrenal gland
S0044801 Gland Disease, Adrenal
[…]

Term
L0041793

S0860744 *Disorder of adrenal gland, unspecified*
S0217833 Unspecified disorder of adrenal glands

Term
L0161347

S0225481 *ADRENAL DISORDER*
S0627685 DISORDER ADRENAL (NOS)
[…]

Term
L0181041

S0632950 *Disorder of adrenal gland*
S0354509 Adrenal Gland Disorders
[…]

Term
L0368399

S0586222 *Adrenal disease*
S0466921 ADRENAL DISEASE, NOS
[…]

Term
L1279026

S1520972 *Nebennierenkrankheiten* GER

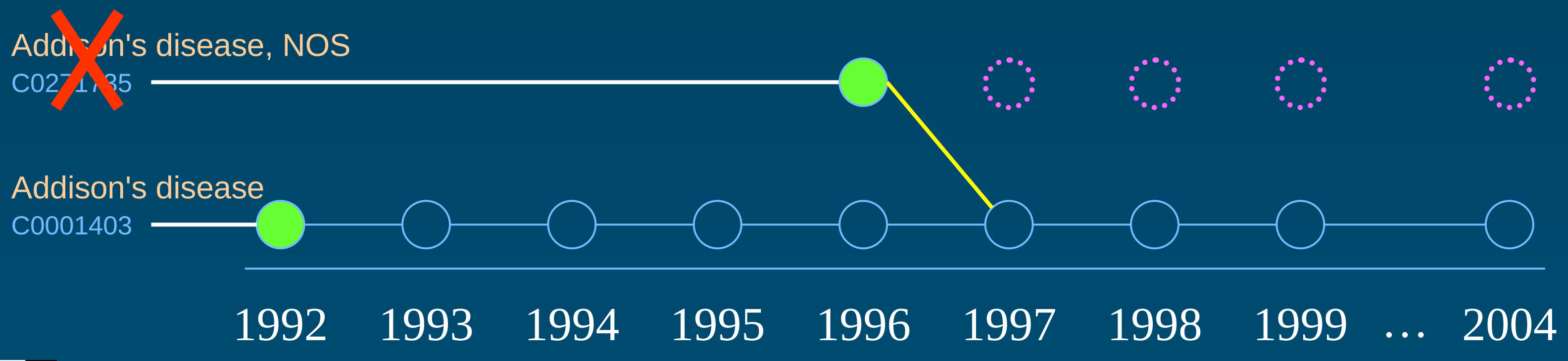
Term
L0162317

S0226798 *SURRENALE, MALADIES* FRE

[…]

Metathesaurus Evolution over time

- Concepts never die (in principle)
  - CUIs are permanent identifiers
- What happens when they do die (in reality)?
  - Concepts can merge or split
  - Resulting in new concepts and deletions



Metathesaurus Relationships

- Symbolic relations: ~9 M pairs of concepts
- Statistical relations : ~7 M pairs of concepts (co-occurring concepts)
- Mapping relations: 100,000 pairs of concepts

- Categorization: Relationships between concepts and semantic types from the Semantic Network

Symbolic relations

- Relation
  - Pair of “atom” identifiers
  - Type
  - Attribute (if any)
  - List of sources (for type and attribute)
- Semantics of the relationship:
  defined by its type [and attribute]

Source transparency: the information
is recorded at the “atom” level

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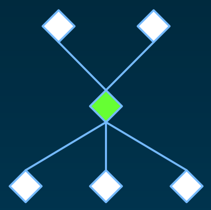
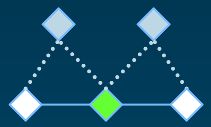
Symbolic relationships Type

- Hierarchical
  - Parent / Child **PAR/CHD**
  - Broader / Narrower than **RB/RN**



- Derived from hierarchies
  - Siblings (children of parents) **SIB**



- Associative
  - Other **RO**

- Various flavors of near-synonymy
  - Similar **RL**
  - Source asserted synonymy **SY**
  - Possible synonymy **RQ**

Symbolic relationships Attribute

- Hierarchical
  - isa (is-a-kind-of)
  - part-of
- Associative
  - location-of
  - caused-by
  - treats
  - …
- Cross-references (mapping)

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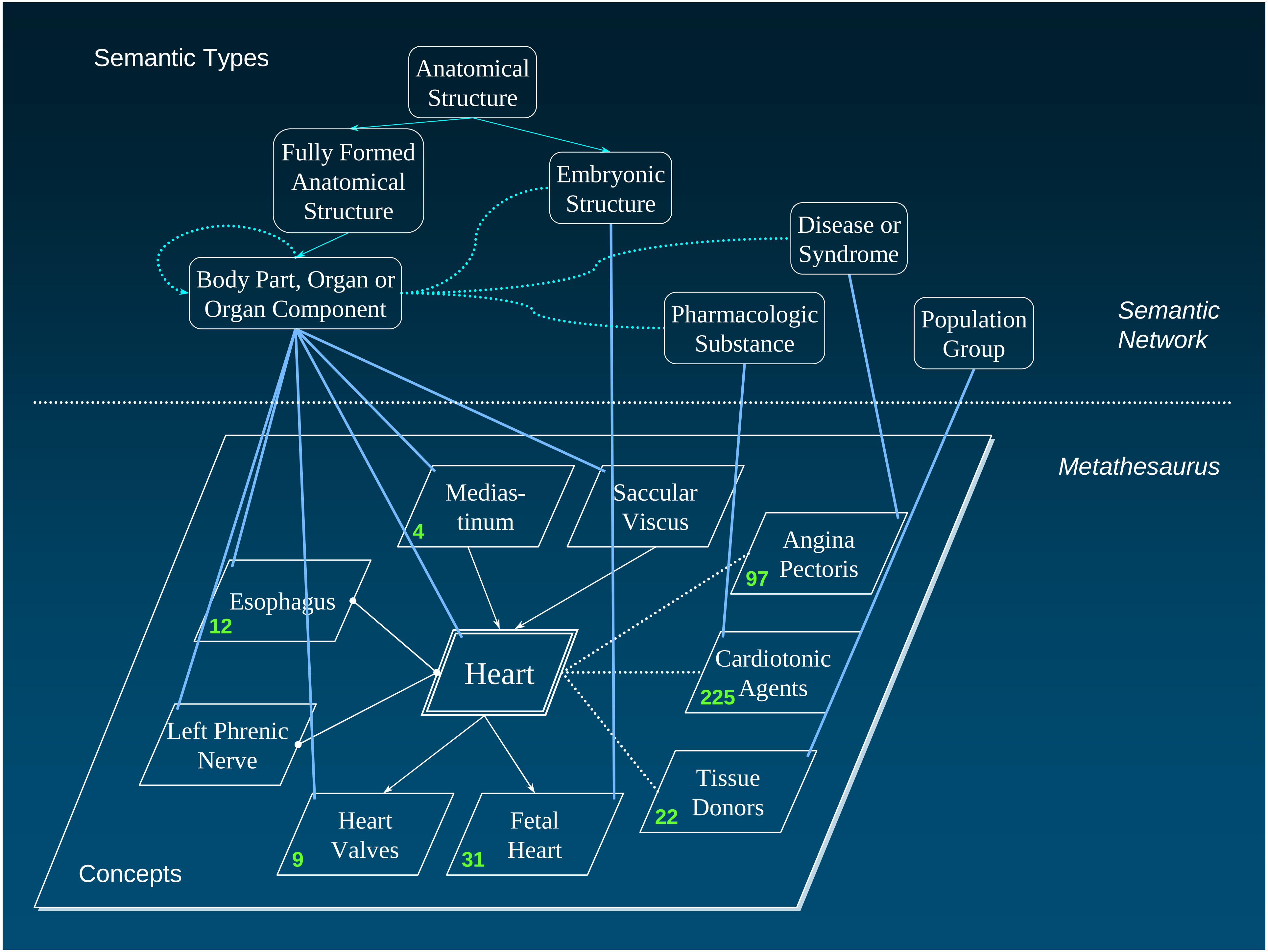
Semantic Types
Anatomical Structure
Fully Formed Anatomical Structure
Embryonic Structure
Body Part, Organ or Organ Component
Disease or Syndrome
Pharmacologic Substance
Population Group
Semantic Network
Metathesaurus
Medias-tinum
4
Saccular Viscus
Angina Pectoris
97
Esophagus
12
Heart
Cardiotonic Agents
225
Left Phrenic Nerve
Tissue Donors
22
Heart Valves
9
Fetal Heart
31
Concepts

UMLS Semantic Network

Semantic Network

- Semantic types (135)
  - tree structure
  - 2 major hierarchies
    - Entity
      - Physical Object
      - Conceptual Entity
    - Event
      - Activity
      - Phenomenon or Process

Semantic Network

- Semantic network relationships (54)
  - hierarchical (isa = is a kind of)
    - among types
      - Animal *isa* Organism
      - Enzyme *isa* Biologically Active Substance
    - among relations
      - treats *isa* affects
  - non-hierarchical
    - Sign or Symptom *diagnoses* Pathologic Function
    - Pharmacologic Substance *treats* Pathologic Function

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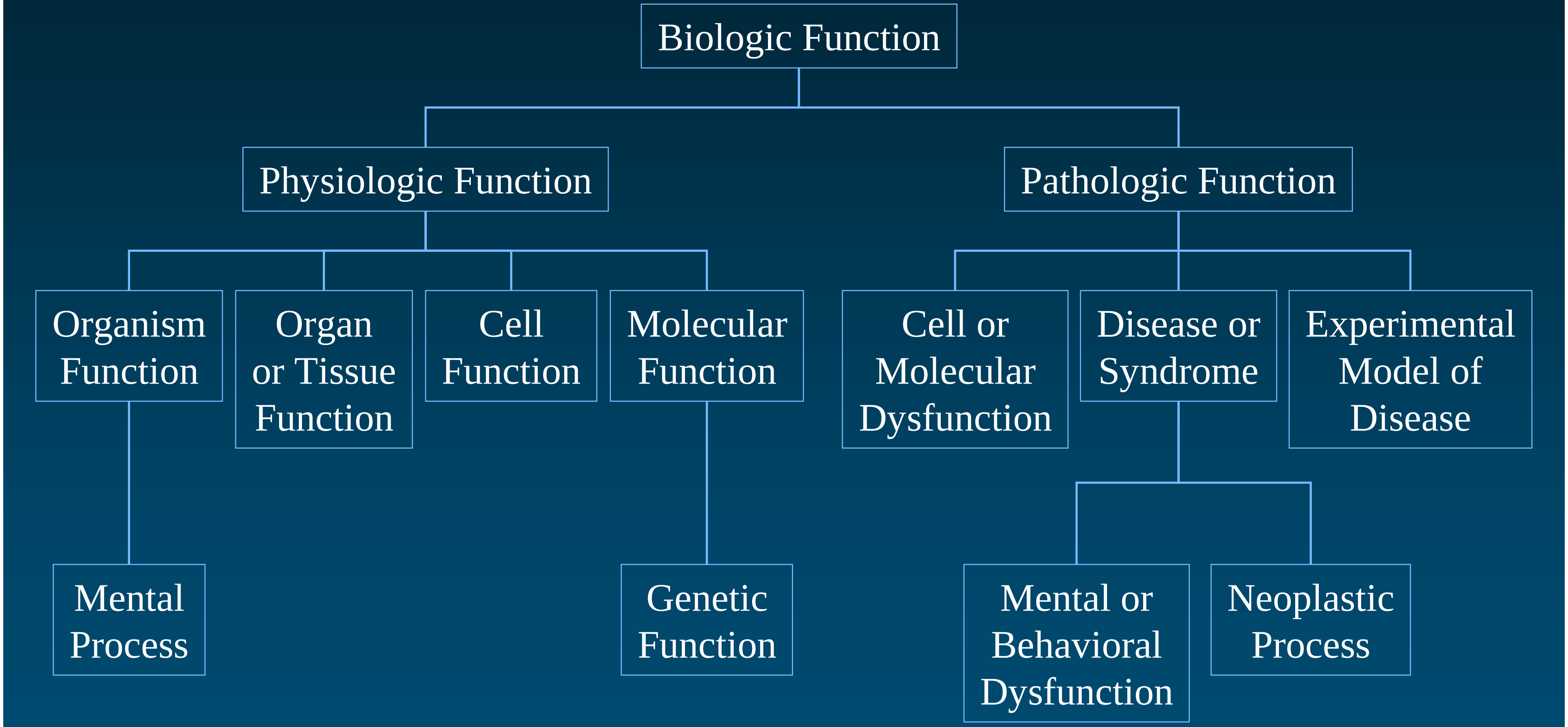
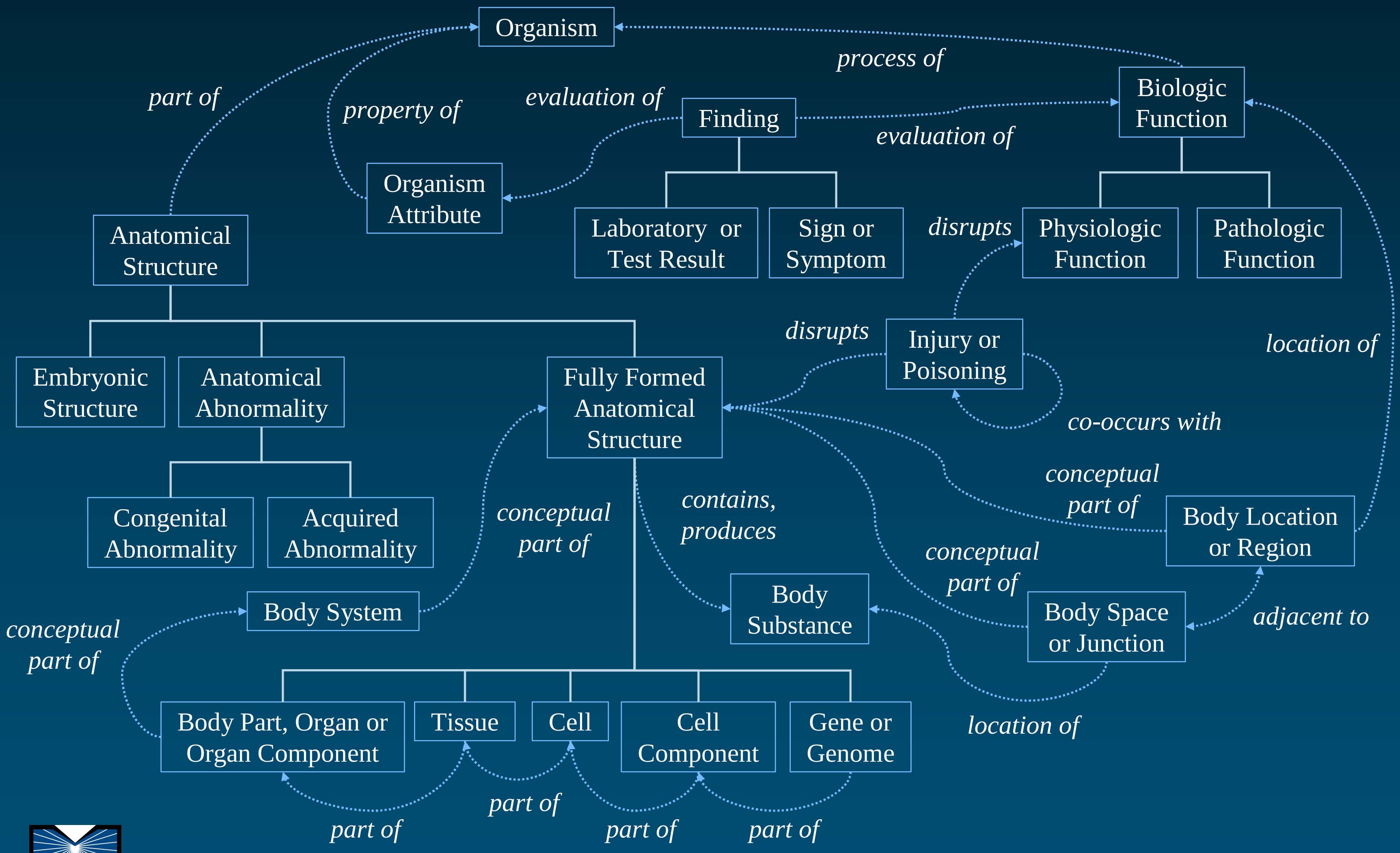
“Biologic Function” hierarchy (isa)



Associative (non-isa) relationships



Why a semantic network?

- Semantic Types serve as high level categories assigned to Metathesaurus concepts, *independently of their position in a hierarchy*

- A relationship between 2 Semantic Types (ST) is a possible link between 2 concepts that have been assigned to those STs
  - The relationship may or may not hold at the concept level
  - Other relationships may apply at the concept level

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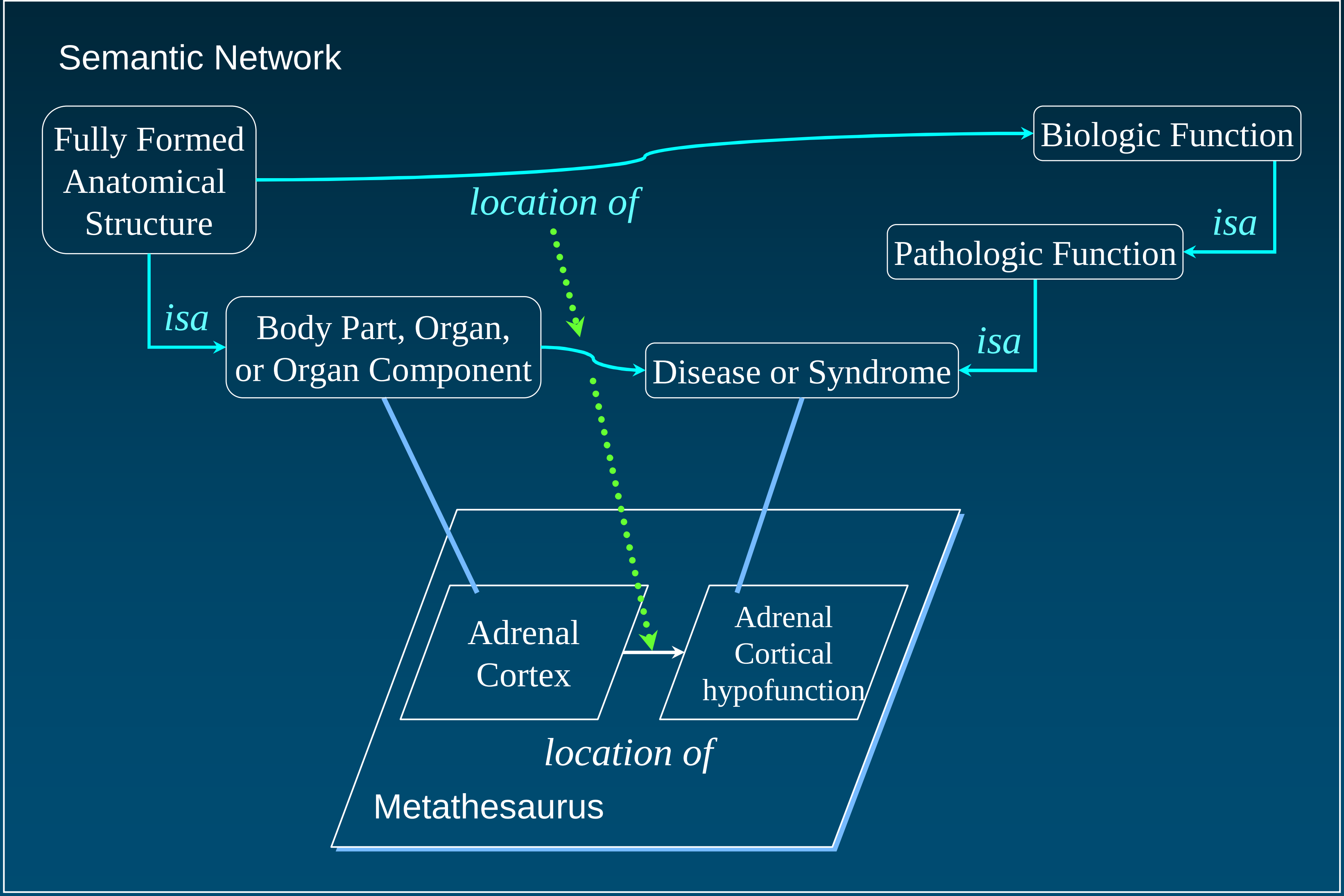
Relationships can inherit semantics



SPECIALIST Lexicon and lexical tools

SPECIALIST Lexicon

- Content
  - English lexicon
  - Many words from the biomedical domain
- 200,000+ lexical items
- Word properties
  - morphology
  - orthography
  - syntax
- Used by the lexical tools

Morphology

- Inflection

noun	nucleus, nuclei
verb	cauterize, cauterizes, cauterized, cauterizing
adjective	red, redder, reddest

- Derivation

verb	↔	noun	cauterize -- cauterization
adjective	↔	noun	red -- redness

Orthography

- Spelling variants

oe/e	oesophagus - esophagus
ae/e	anaemia - anemia
ise/ize	cauterise - cauterize
genitive mark	Addison's disease Addison disease Addisons disease

Syntax

- Complementation
  - verbs

intransitive	I'll treat.
transitive	He treated the patient.
ditransitive	He treated the patient with a drug.

- nouns
  - prepositional phrase

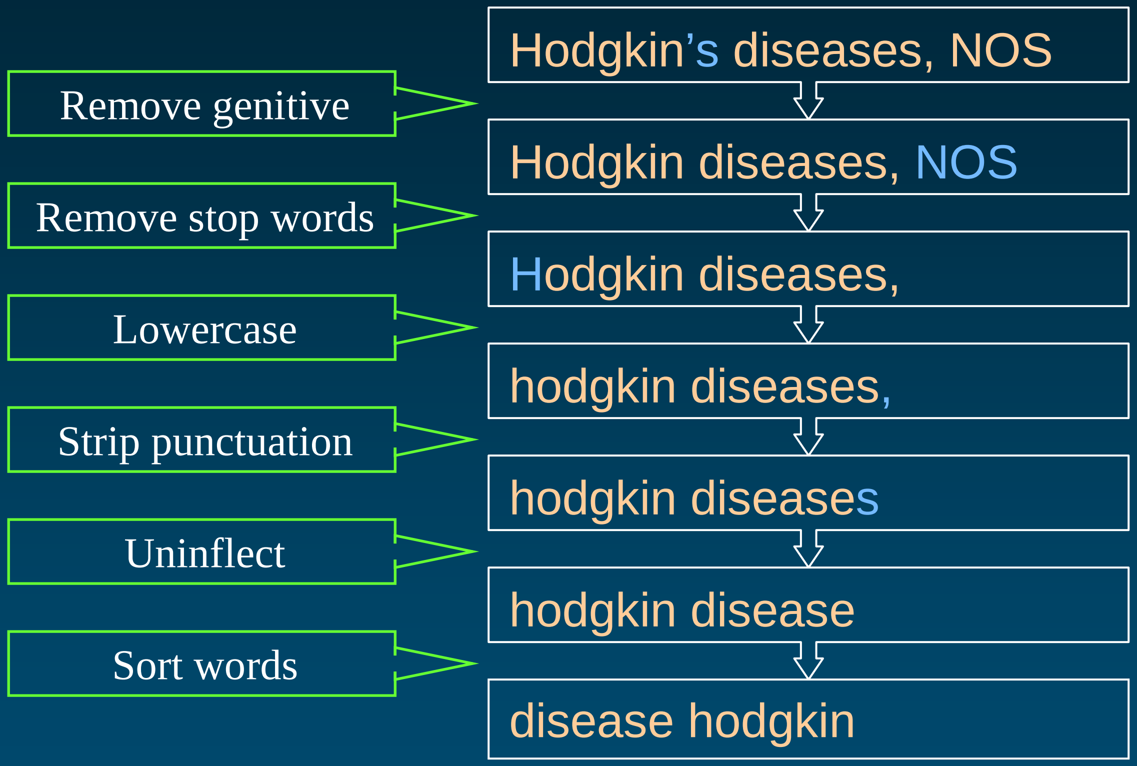
Valve of coronary sinus

- Position for adjectives

Lexical tools

- To manage lexical variation in biomedical terminologies
- Major tools
  - Normalization
  - Indexes
  - Lexical Variant Generation program (lvg)
- Based on the SPECIALIST Lexicon
- Used by noun phrase extractors, search engines

Normalization



Hodgkin’s diseases, NOS

Remove genitive

Hodgkin diseases, NOS

Remove stop words

Hodgkin diseases,

Lowercase

hodgkin diseases,

Strip punctuation

hodgkin diseases

Uninflect

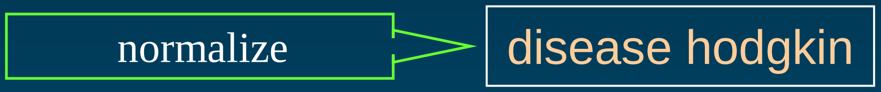
hodgkin disease

Sort words

disease hodgkin

Normalization: Example

Hodgkin Disease
HODGKINS DISEASE
Hodgkin's Disease
Disease, Hodgkin's
Hodgkin's, disease
HODGKIN'S DISEASE
Hodgkin's disease
Hodgkins Disease
Hodgkin's disease NOS
Hodgkin's disease, NOS
Disease, Hodgkins
Diseases, Hodgkins
Hodgkins Diseases
Hodgkins disease
hodgkin's disease
Disease, Hodgkin



normalize

disease hodgkin

Normalization Applications

- Model for lexical resemblance
- Help find lexical variants for a term
  - Terms that normalize the same usually share the same LUI
- Help find candidates to synonymy among terms
- Help map input terms to UMLS concepts

Indexes

- Word index
  - word to Metathesaurus strings
  - one word index per language
- Normalized word index
  - normalized word to Metathesaurus strings
  - English only
- Normalized string index
  - normalized term to Metathesaurus strings
  - English only

Lexical Variant Generation program

- Tool for specialists (linguists)
- Performs atomic lexical transformations
  - generating inflectional variants
  - lowercase
  - …
- Performs sequences of atomic transformations
  - a specialized sequence of transformations provides the normalized form of a term (the *norm* program)

UMLS in action

MetaMap

MetaMap Motivation

[Aronson, *AMIA*, 2001]

- Term extraction
  - Identifying UMLS concepts from text
- Usage
  - Information indexing and retrieval
  - Knowledge extraction / discovery
  - Semantic interpretation
- Characteristics
  - Linguistic approach
  - Based on UMLS knowledge sources

MetaMap Methods

- Parsing
  - Shallow syntactic analysis
  - SPECIALIST lexicon
  - Xerox part-of-speech tagger
- Variant generation
- Candidate retrieval
  - Retrieve candidate terms containing at least one variant
- Candidate evaluation
  - Rank candidate terms with respect to closeness to input text (centrality, variation, coverage, and cohesiveness)

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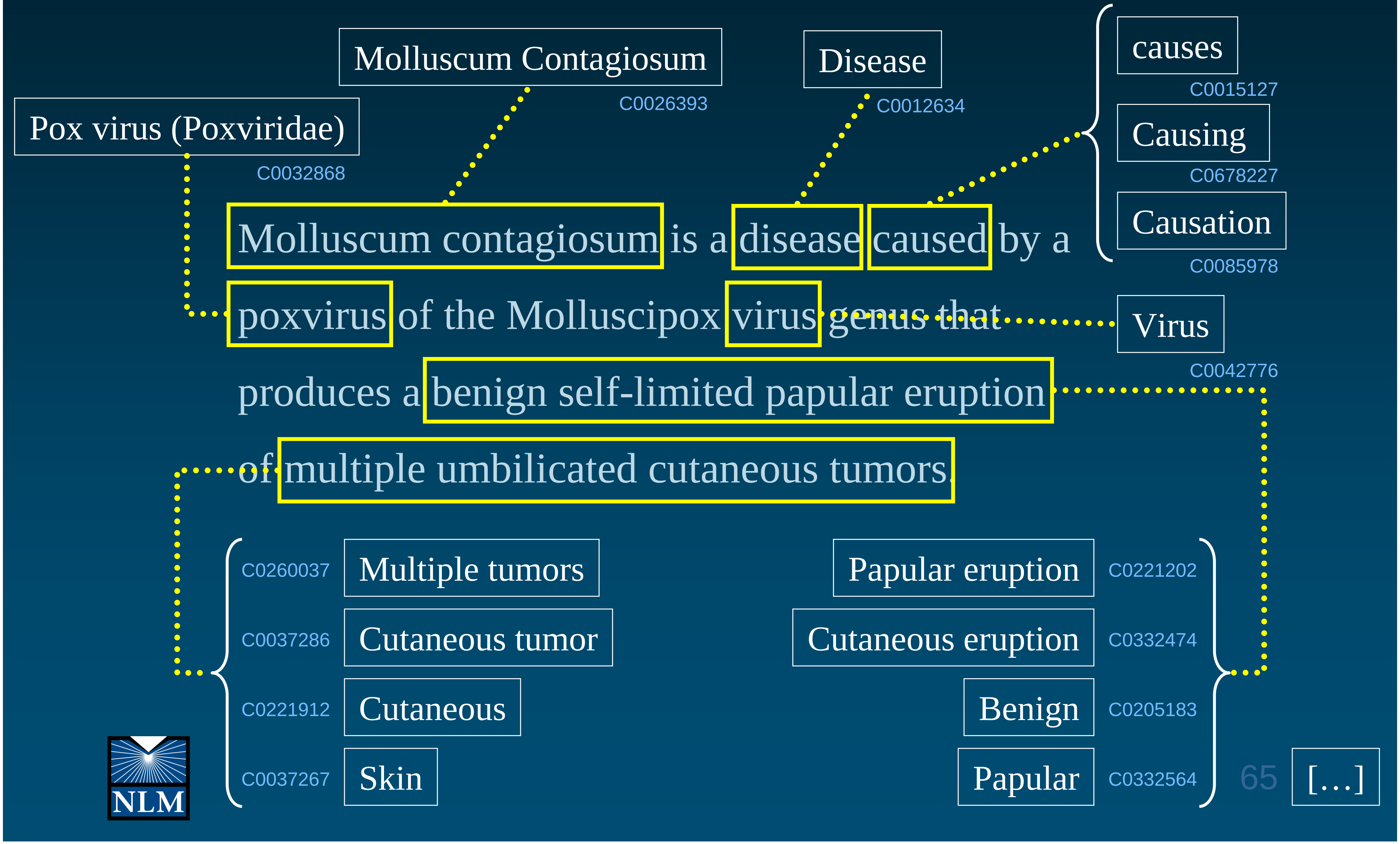
MetaMap Example



Molluscum contagiosum is a disease caused by a poxvirus of the Molluscipox virus genus that produces a benign self-limited papular eruption of multiple umbilicated cutaneous tumors.

Molluscum Contagiosum C0026393

Disease C0012634

causes C0015127

Causing C0678227

Causation C0085978

Pox virus (Poxviridae) C0032868

Virus C0042776

C0260037 Multiple tumors

C0037286 Cutaneous tumor

C0221912 Cutaneous

C0037267 Skin

Papular eruption C0221202

Cutaneous eruption C0332474

Benign C0205183

Papular C0332564

[…]

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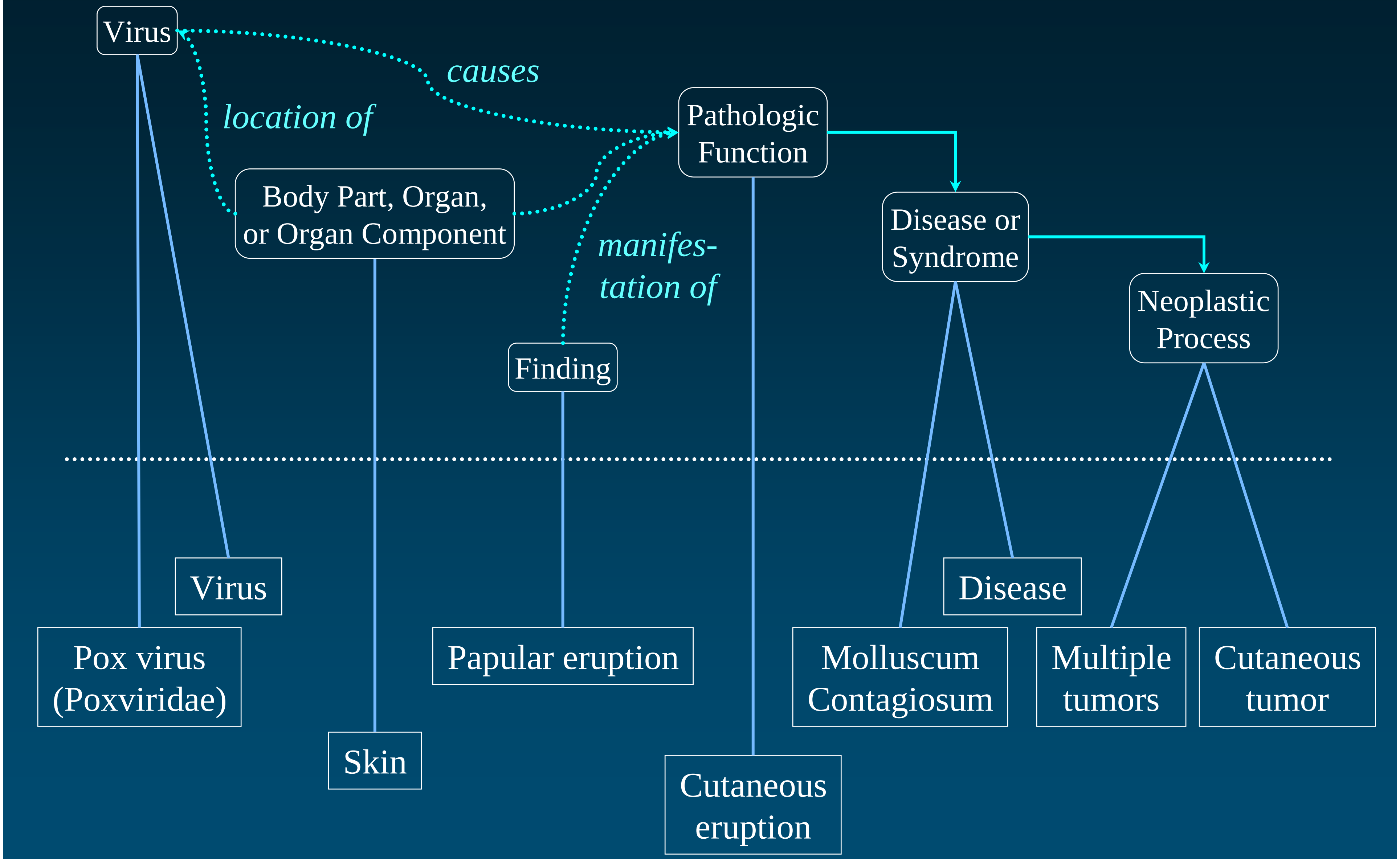
Semantic Network



Virus

causes

location of

Pathologic Function

Body Part, Organ, or Organ Component

Disease or Syndrome

manifestation of

Neoplastic Process

Finding

Virus

Disease

Pox virus (Poxviridae)

Papular eruption

Molluscum Contagiosum

Multiple tumors

Cutaneous tumor

Skin

Cutaneous eruption

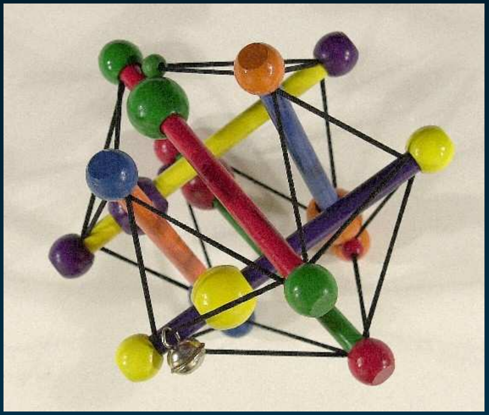
Metathesaurus

Using MetaMap MMTx

- Requires UMLS license
- Local implementation (Java-based)
- Provides
  - Stand-alone application
  - API for integrating in other applications

http://mmtx.nlm.nih.gov

NLM



Medical Ontology Research

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NATIONAL LIBRARY OF MEDICINE

Olivier Bodenreider

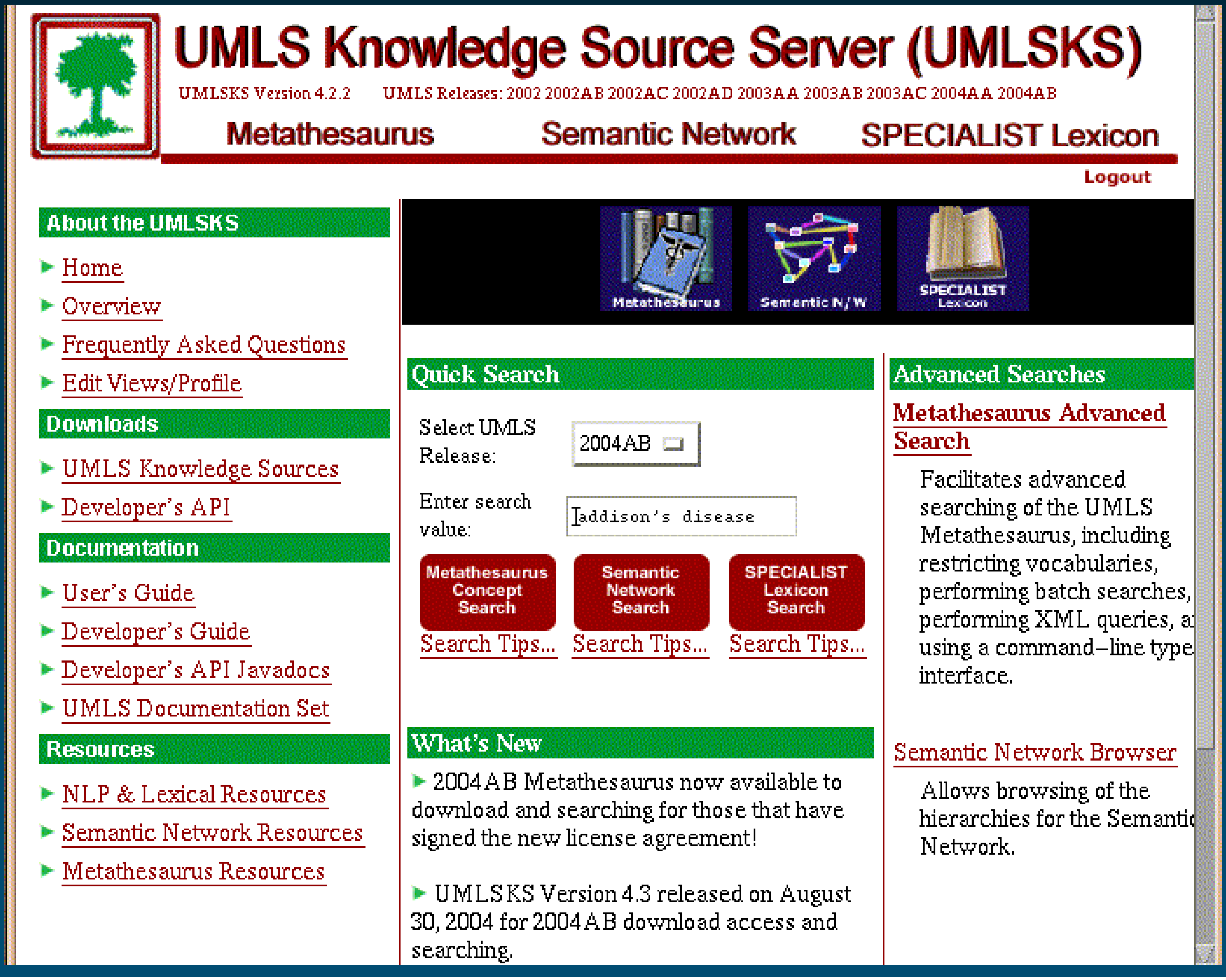
Lister Hill National Center
for Biomedical Communications
Bethesda, Maryland - USA

Appendix

Knowledge Source Server
Web Interface

http://umlsks.nlm.nih.gov

UMLS Knowledge Source Server Home Page



UMLSKS Version 4.2.2   UMLS Releases: 2002 2002AB 2002AC 2002AD 2003AA 2003AB 2003AC 2004AA 2004AB

Select UMLS Release: 2004AB

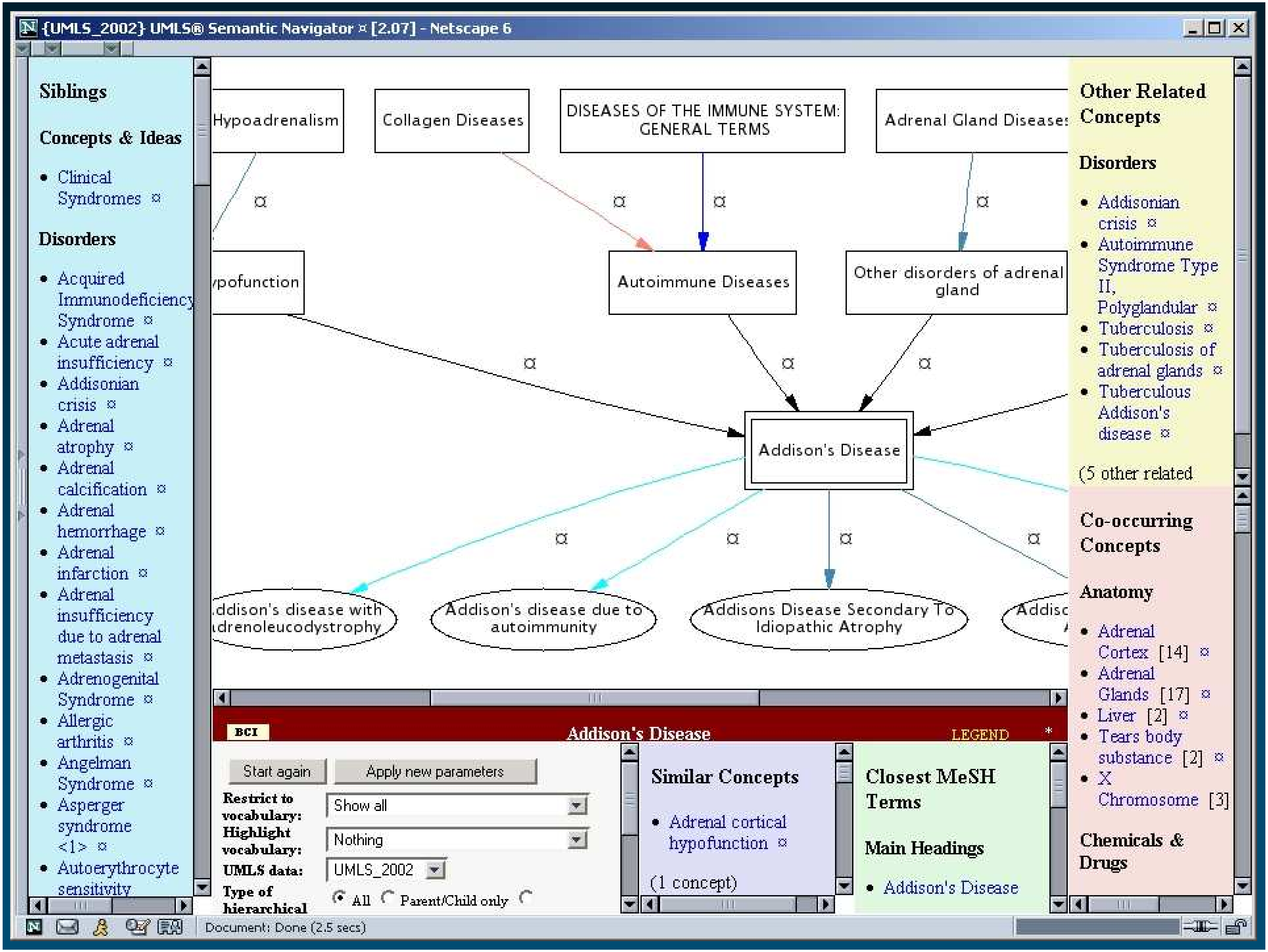
Enter search value: addison's disease

2004AB Metathesaurus now available to download and searching for those that have signed the new license agreement!

UMLSKS Version 4.3 released on August 30, 2004 for 2004AB download access and searching.

Facilitates advanced searching of the UMLS Metathesaurus, including restricting vocabularies, performing batch searches, performing XML queries, a using a command–line type interface.

Allows browsing of the hierarchies for the Semantic Network.



{UMLS_2002} UMLS® Semantic Navigator ¤ [2.07] - Netscape 6

Siblings

Concepts & Ideas

- Clinical Syndromes ¤

Disorders

- Acquired Immunodeficiency Syndrome ¤
- Acute adrenal insufficiency ¤
- Addisonian crisis ¤
- Adrenal atrophy ¤
- Adrenal calcification ¤
- Adrenal hemorrhage ¤
- Adrenal infarction ¤
- Adrenal insufficiency due to adrenal metastasis ¤
- Adrenogenital Syndrome ¤
- Allergic arthritis ¤
- Angelman Syndrome ¤
- Asperger syndrome <1> ¤
- Autoerythrocyte sensitivity

Hypoadrenalism
Collagen Diseases
DISEASES OF THE IMMUNE SYSTEM: GENERAL TERMS
Adrenal Gland Diseases
ypofunction
Autoimmune Diseases
Other disorders of adrenal gland
Addison's Disease
ddison's disease with drenoleucodystrophy
Addison's disease due to autoimmunity
Addisons Disease Secondary To Idiopathic Atrophy
Addisc
¤

Other Related Concepts

Disorders

- Addisonian crisis ¤
- Autoimmune Syndrome Type II, Polyglandular ¤
- Tuberculosis ¤
- Tuberculosis of adrenal glands ¤
- Tuberculous Addison's disease ¤

(5 other related

Co-occurring Concepts

Anatomy

- Adrenal Cortex [14] ¤
- Adrenal Glands [17] ¤
- Liver [2] ¤
- Tears body substance [2] ¤
- X Chromosome [3]

Chemicals & Drugs

BCI

Addison's Disease

Restrict to vocabulary: Show all

Highlight vocabulary: Nothing

UMLS data: UMLS_2002

Type of hierarchical: ● All ○ Parent/Child only ○

Similar Concepts

- Adrenal cortical hypofunction ¤

(1 concept)

Closest MeSH Terms

Main Headings

- Addison's Disease

Document: Done (2.5 secs)

Knowledge Source Server
Application Programming Interface

UMLSKS API basics

- Remote server at NLM
- Local application connected through

Java RMI

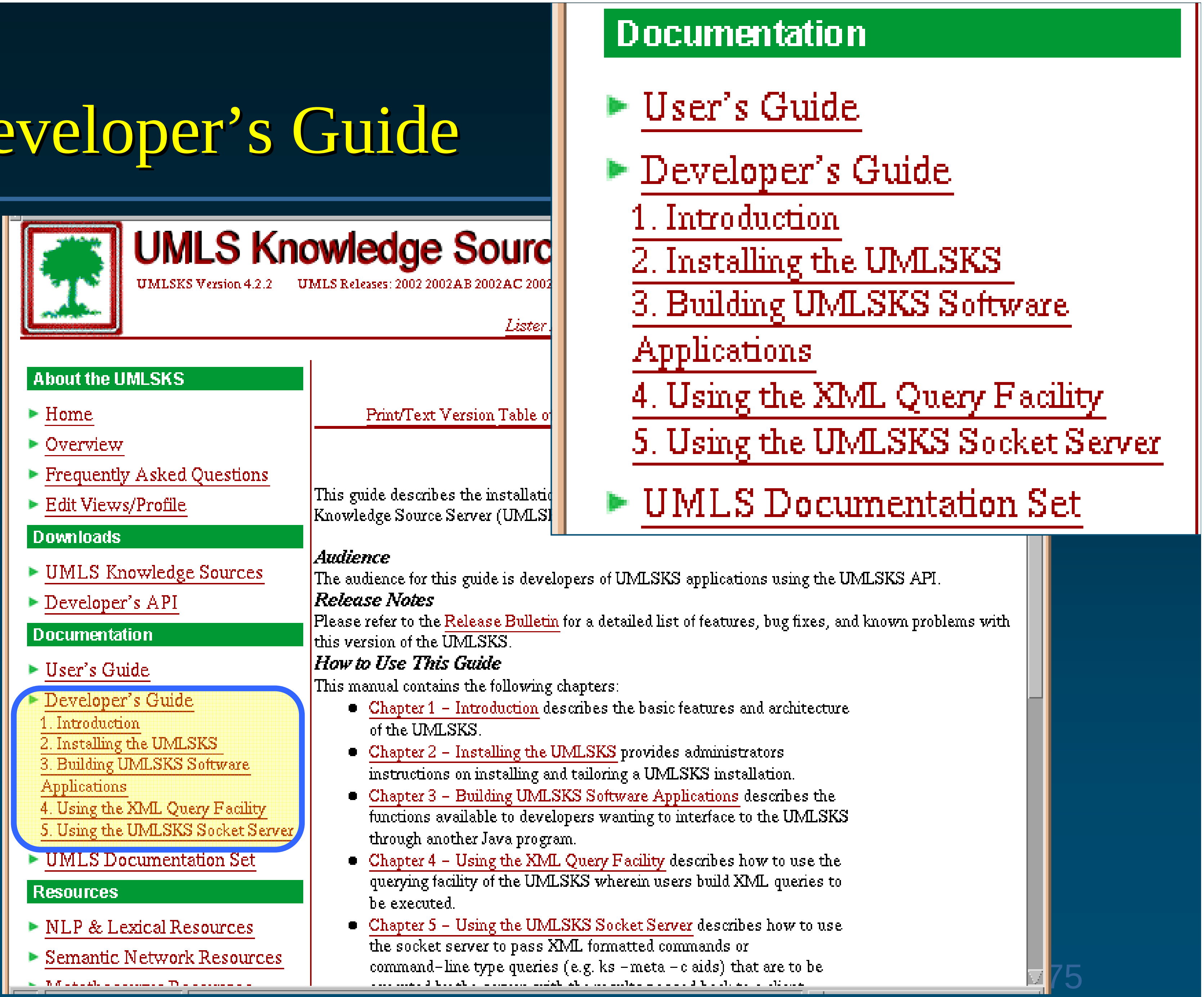
- Java-based applications
- Developer’s Guide: Chapter 3
- Set of Java classes (part of the UMLSKS API download)
- Detailed *Javadoc* documentation online and with API download

TCP/IP socket

- XML-based queries
- Developer’s Guide: Chapter 5
- XML schema
- Socket server
  - Host: umlsks.nlm.nih.gov
  - Port: 8042

NLM

Developer’s Guide



Documentation

- User’s Guide
- Developer’s Guide
  1. Introduction
  2. Installing the UMLSKS
  3. Building UMLSKS Software Applications
  4. Using the XML Query Facility
  5. Using the UMLSKS Socket Server
- UMLS Documentation Set

UMLS Knowledge Sourc

UMLSKS Version 4.2.2 UMLS Releases: 2002 2002AB 2002AC 2002

Lister

About the UMLSKS

- Home
- Overview
- Frequently Asked Questions
- Edit Views/Profile

Downloads

- UMLS Knowledge Sources
- Developer’s API

Documentation

- User’s Guide
- Developer’s Guide
  1. Introduction
  2. Installing the UMLSKS
  3. Building UMLSKS Software Applications
  4. Using the XML Query Facility
  5. Using the UMLSKS Socket Server
- UMLS Documentation Set

Resources

- NLP & Lexical Resources
- Semantic Network Resources

Print/Text Version Table of

This guide describes the installatio
Knowledge Source Server (UMLSI

Audience

The audience for this guide is developers of UMLSKS applications using the UMLSKS API.

Release Notes

Please refer to the Release Bulletin for a detailed list of features, bug fixes, and known problems with this version of the UMLSKS.

How to Use This Guide

This manual contains the following chapters:

- Chapter 1 – Introduction describes the basic features and architecture of the UMLSKS.
- Chapter 2 – Installing the UMLSKS provides administrators instructions on installing and tailoring a UMLSKS installation.
- Chapter 3 – Building UMLSKS Software Applications describes the functions available to developers wanting to interface to the UMLSKS through another Java program.
- Chapter 4 – Using the XML Query Facility describes how to use the querying facility of the UMLSKS wherein users build XML queries to be executed.
- Chapter 5 – Using the UMLSKS Socket Server describes how to use the socket server to pass XML formatted commands or command-line type queries (e.g. ks -meta -c aids) that are to be

MetamorphoSys

What is MetamorphoSys?

- Tool distributed with the UMLS
- Multi-platform Java software
- The UMLS installation and customization wizard
  - Installs Knowledge Sources to local storage
  - Subsets and customizes a local Metathesaurus

NLM

Why use MetamorphoSys?

Customize the Metathesaurus

- To remove terminology that is unhelpful, or even harmful, to your needs and purposes
- To comply with terms of license agreement

Changing Default Settings

- To alter the preferred name
- To alter suppressibility of specific source term types

Bibliography

UMLS documentation and support

- UMLS homepage http://umlsinfo.nlm.nih.gov/
  - with links to all other UMLS information
- UMLSKS homepage http://umlsks.nlm.nih.gov/
  - with links to the User’s and Developer’s guides
- Email address for support custserv@nlm.nih.gov

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References

- UMLS as a research project
  - Lindberg, D. A., Humphreys, B. L., & McCray, A. T. (1993). The Unified Medical Language System. *Methods Inf Med, 32*(4), 281-91.
  - Humphreys, B. L., Lindberg, D. A., Schoolman, H. M., & Barnett, G. O. (1998). The Unified Medical Language System: an informatics research collaboration. *J Am Med Inform Assoc, 5*(1), 1-11.
  - Bodenreider O. (2004). The Unified Medical Language System (UMLS): Integrating biomedical terminology. *Nucleic Acids Research*; D267-D270.

NLM

References

- Technical papers
  - McCray, A. T., & Nelson, S. J. (1995). The representation of meaning in the UMLS. *Methods Inf Med*, *34*(1-2), 193-201.
  - Campbell, K. E., Oliver, D. E., Spackman, K. A., & Shortliffe, E. H. (1998). Representing thoughts, words, and things in the UMLS. *J Am Med Inform Assoc*, *5*(5), 421-31.
- Comprehensive bibliography 1986-96

http://www.nlm.nih.gov/pubs/cbm/umlscbm.html